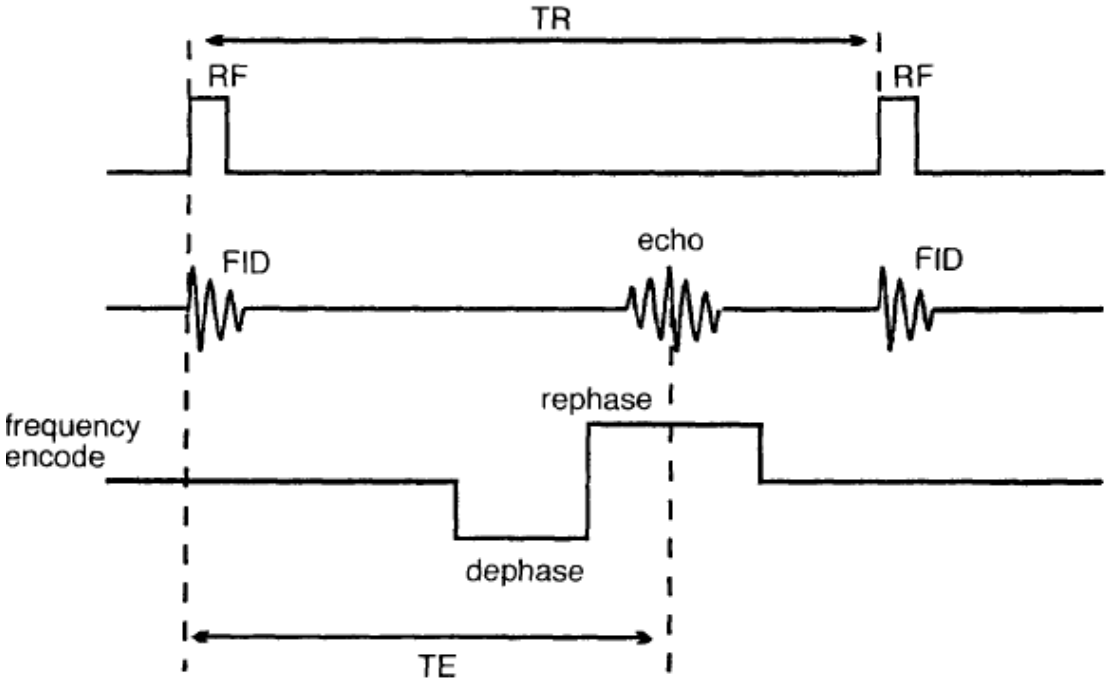
GRADIENT ECHO PULSE SEQUENCES

1) Conventional gradient echo pulse sequence : see before

- The frequency encoding gradient is initially applied negatively to speed up the dephasing of the fID, and then its polarity is reversed producing rephasing of the gradient echo.

Uses

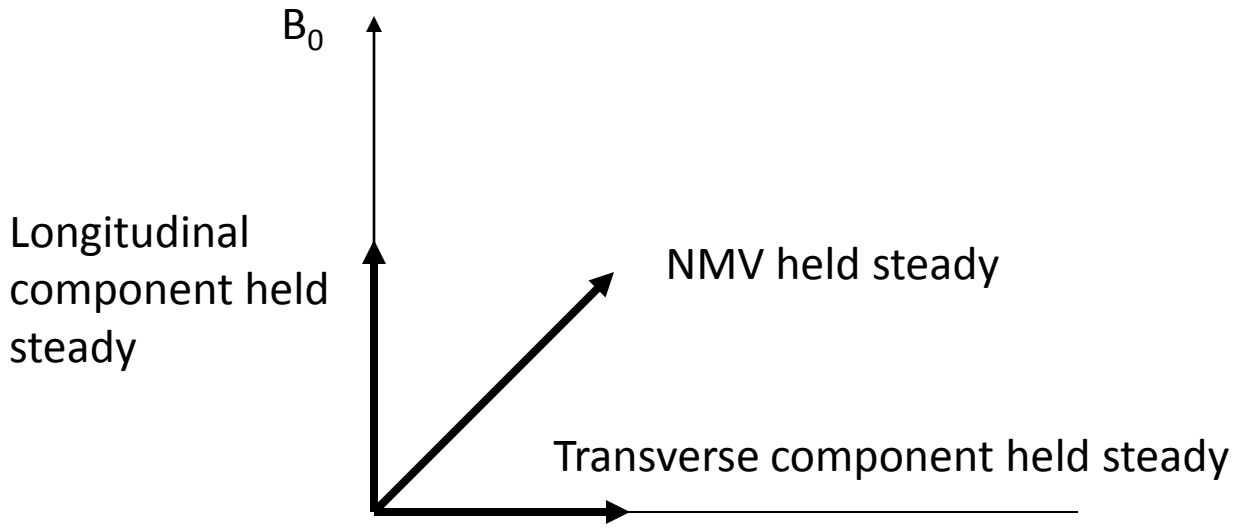
- to acquire T2*, T1, and proton density weighting.
- allow for a reduction in the scan time as the TR is greatly reduced → can be used for rapid studies (e.g. single slice breath-hold abdomen imaging and dynamic contrast enhancement imaging)..
- may be used to produce angiographic type images (see later)



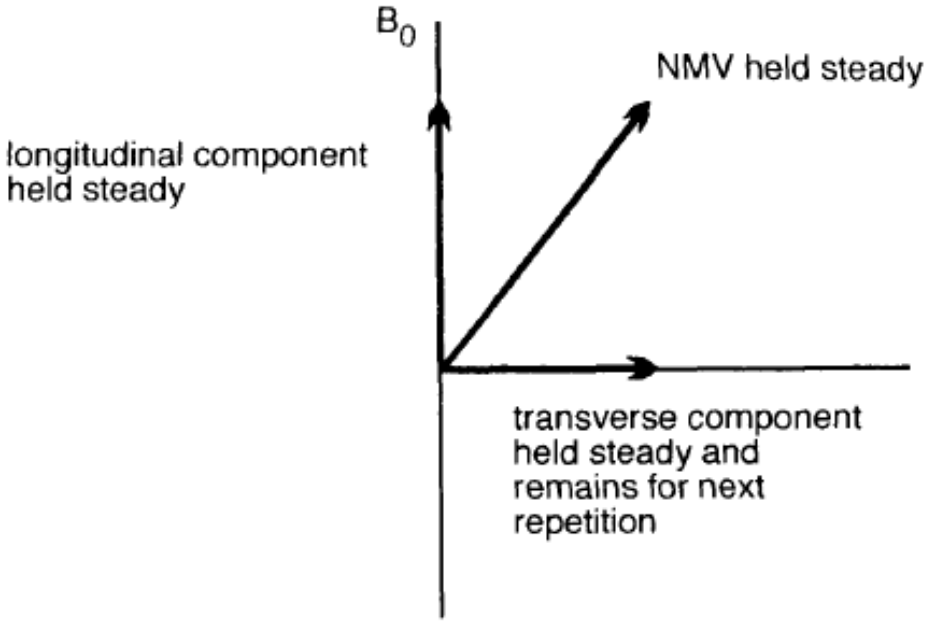
2) Pulse sequences that use the steady state

steady state:

- condition where the TR is shorter than the T1 and T2 times of the tissues→ no time for the transverse magnetisation to decay before the pulse sequence is repeated again.
- The flip angle and the TR maintain the steady state which holds the longitudinal and transverse components of magnetisation during the data acquisition
- angles of 30° to 45° in conjunction with a TR of 20 to 50 ms achieves the steady state.



- ***residual transverse magnetisation:***
  - transverse magnetisation, produced as a result of previous excitations (have time to decay)
  - affects image contrast as it induces a voltage in the receiver coil. → tissues with long T2 times appear bright on the image.
- Most gradient echo sequences use the steady state as the shortest TR and scan time is achieved.
- Gradient echo sequences that use steady state are classified into:
  - Coherent: residual transverse magnetisation is in phase → T2* WI
  - Incoherent: residual transverse magnetisation is out of phase →T1WI



Echo planar imaging (EPI)

Definition:

MR acquisition method that collects all the data required to fill all the lines of K-space from a single echo train.

i.e. there is no TR: Only one excitation pulse is applied and, from this, data to fill all of K space is acquired (all phase encodings)

Types:

- spin echo EPI: echoes are generated by 180^{o} rephasing pulses
- gradient echo EPI: echoes are generated by gradients

If rephasing RF pulses are exclusively utilized →

RF deposition to the patient would exceed safety limits

the echo train would take so long to perform (most of the signal lost before a satisfactory amount of data could be acquired) as Gradient rephasing is faster

Advantage:

- very rapid data acquisition (images acquired in 50-80 ms).

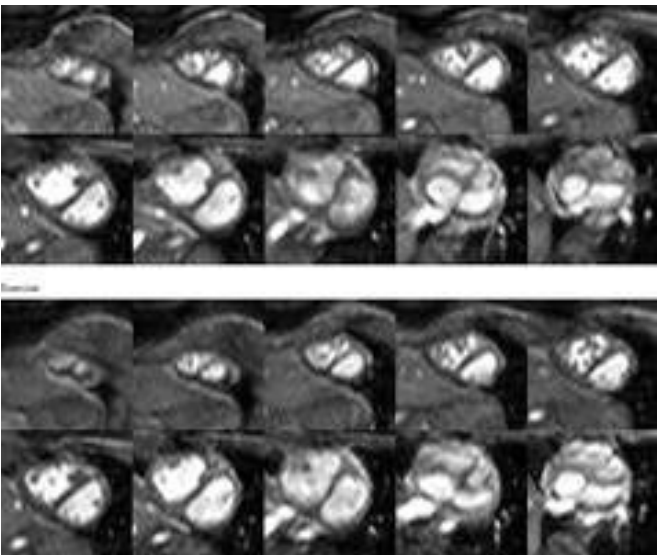
Disadvantage:

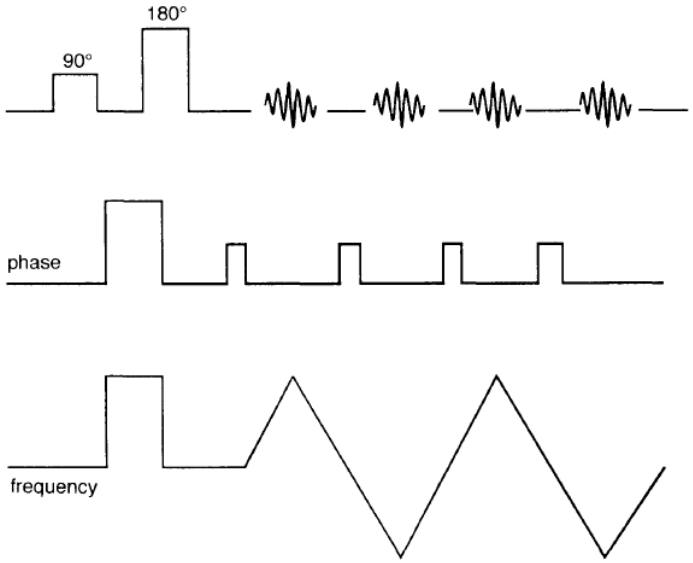
1) place exceptional strains on the gradients
2) Images contain a significant amount of T2* decay because it uses gradient

To compensate for this a modification have been made:

<u>hybrid sequences:</u>

- integrate fast spin echo and EPI
- combine both gradient and RF pulses to generate the echoes in the echo train.
- utilises the benefits of the speed of the gradient *and the ability of the RF* pulse to compensate for T2* effects.
- Increase the scan time to over 100 ms per image





Disadvantage:

3) SNR in the snapshot version of EPI is relatively poor (all k-space lines are filled in the same time).

– can improved by :

- K *space segmentation:*
  - *acquiring a quarter of K space at* a time so that there are four TR periods.
  - This increase the scan time by a factor of four but produce images with improved quality when compared with snapshot acquisitions.

4) fat signal misregisteration.

Fat saturation techniques are commonly required to compensate.

EPI Contrast :

- As all of K space is filled at once, TR is said to equal infinity →Either proton density or T2 weighting is achieved by selecting either a short or long effective TE
- T1 weighting is ONLY possible by applying an inverting pulse prior to the excitation pulse to produce saturation.

Uses :

- Real-time MRI which forms the basis of the new interventional system
- Rapid image acquisition is also ideal for functional imaging
- Increase the use of MR in the chest and abdomen as data acquisition is so rapid physiological motion is frozen.
- Detailed imaging of the heart and coronary vessels are possible

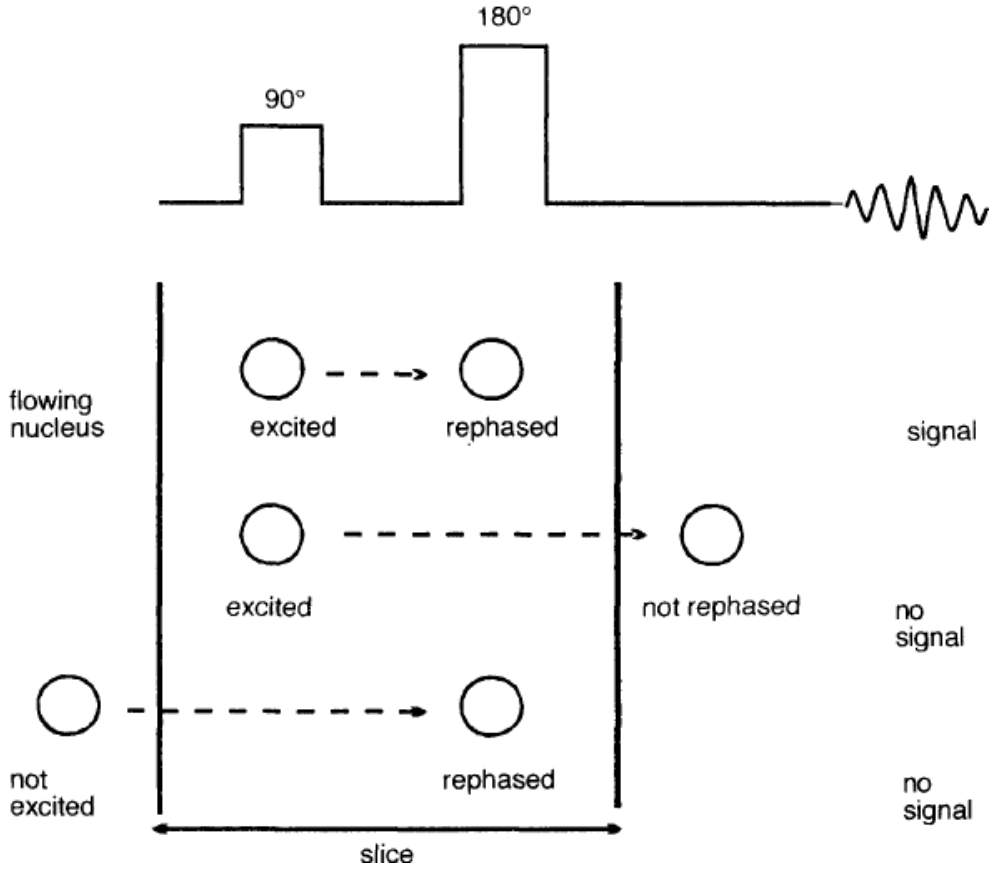
Limitations:

- Concerns over safety: The rapid switching of gradients causes nerve stimulation and gradient noise is severe (ear protection are essential)

MRI Flow Phenomena

Time of flight phenomenon

- In order to produce a signal, a nucleus must receive an excitation pulse and a rephasing pulse.
- Stationary nuclei:
  - Always receive both excitation and rephasing pulses, and produce signal.
- Flowing nuclei:
  - Present in the slice for the excitation may have exited the slice before rephasing, or rephased but not previously exited (*time of flight phenomenon)*

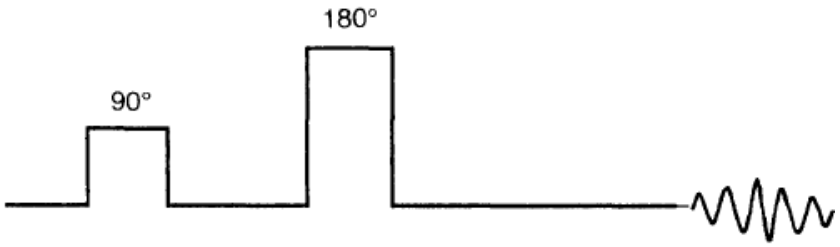


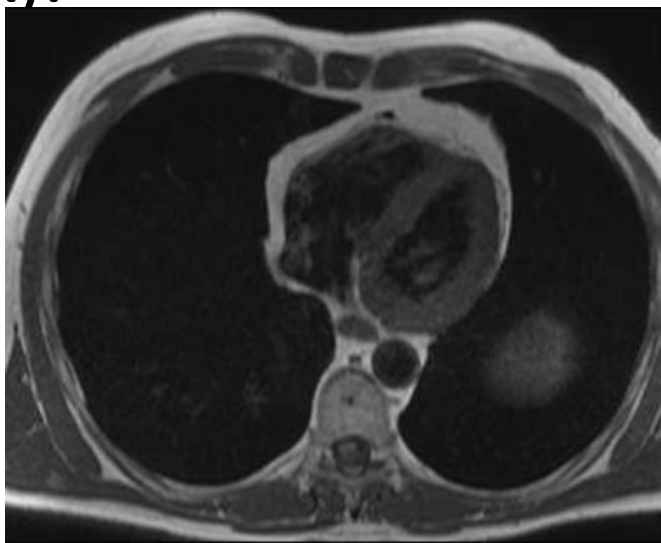
Factors affecting Time of flight phenomenon:

(1) Type of pulse sequence

a) spin echo pulse sequences

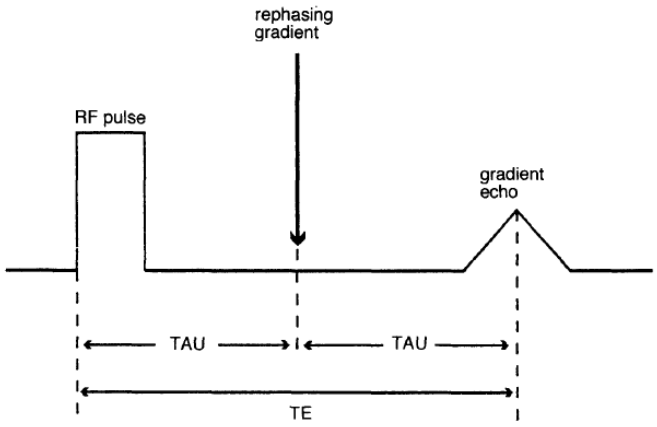
- Every slice is selectively excited and rephased →Time of flight phenomenon will occur, and nuclei flowing perpendicular to the slices to be signal void (vessel appears dark).

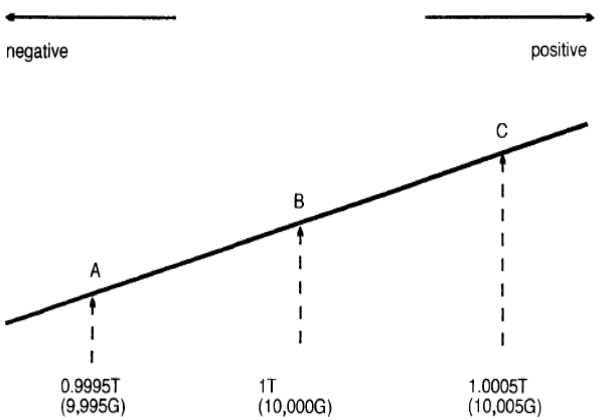


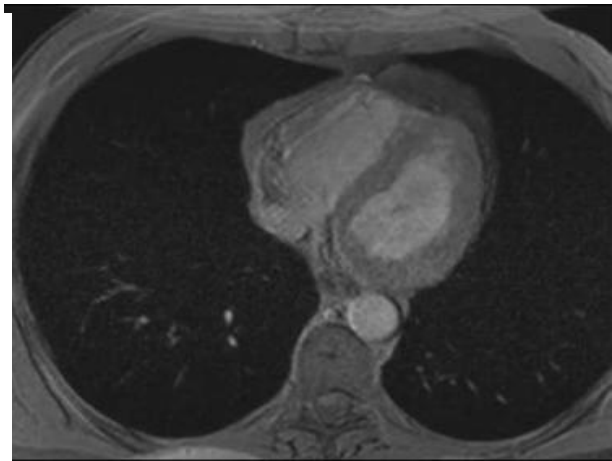


b) Gradient echo pulse sequences:

- Time of flight phenomenon will not occur and flowing nuclei will appear bright because each slice is selectively excited by the RF pulse but the rephasing gradient is applied to the whole body (excitation pulse is slice selective, but the gradient rephasing is not) → flowing nucleus that receives an excitation pulse is rephased regardless of its slice position and produces a signal (flow sensitive).



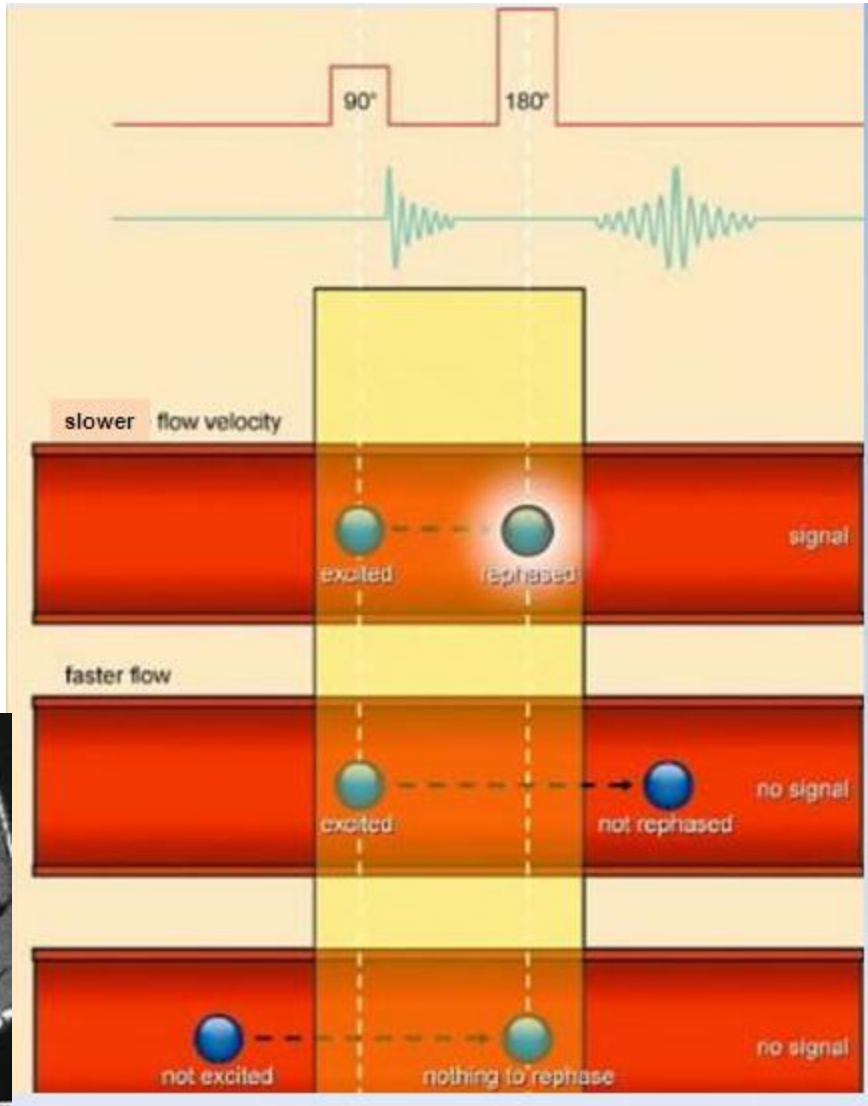


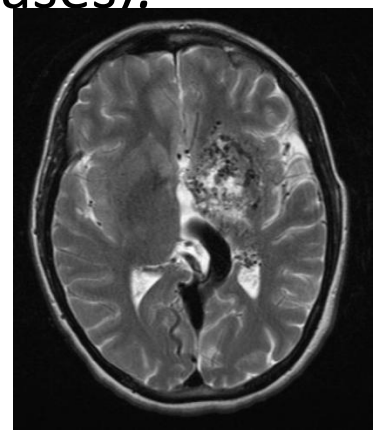


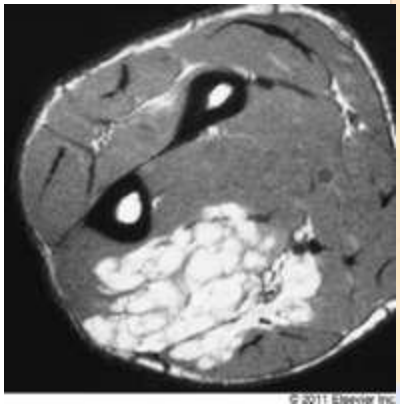
Factors affecting Time of flight phenomenon:

(2) Velocity of blood flow

- High velocity: smaller proportion of flowing nuclei are present in the slice for both the 90º and the 180º RF pulses →time of flight effect increases (= *high velocity signal loss).*
- Slow velocity: a higher proportion of flowing nuclei are present in the slice for both the 90º and the 180º RF pulses → time of flight effect decreases*).*



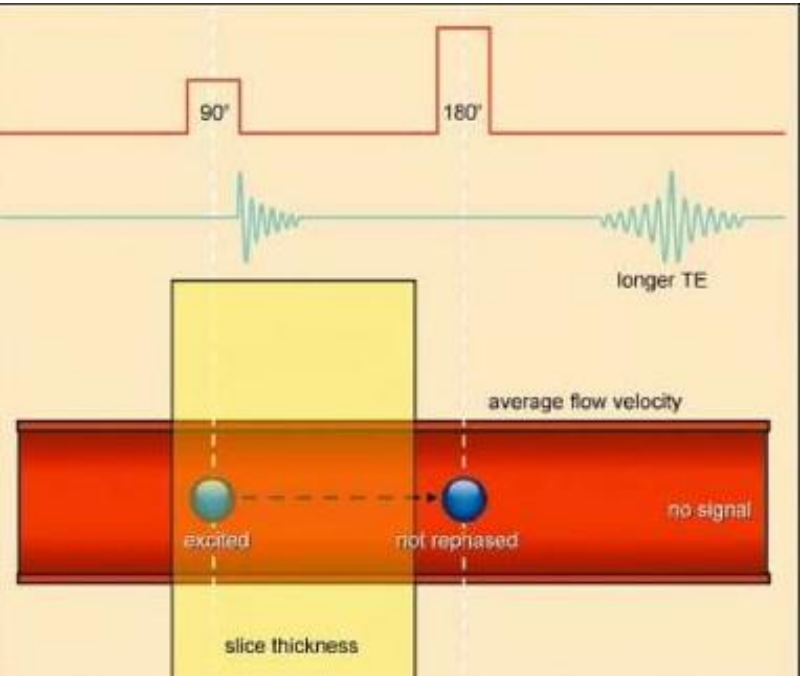


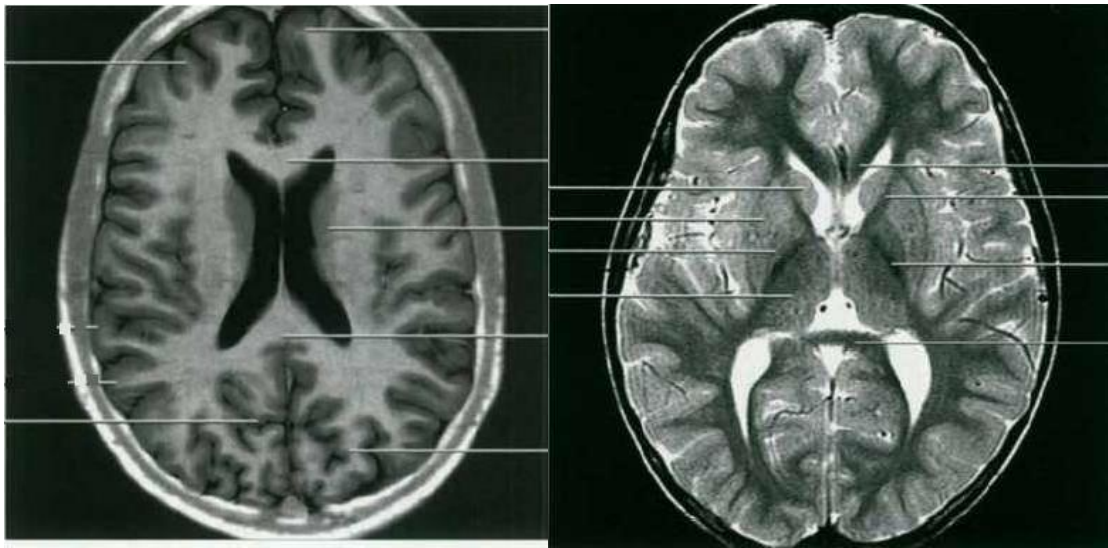


Factors affecting Time of flight phenomenon:

(3) TE

- As the TE increases, a higher proportion of flowing nuclei have exited the slice between the excitation pulse and the 180^{o} rephasing pulse.
- Therefore, at a longer TE the signal void increases.
- i.e. signal void flow is more in T2 than T1WI

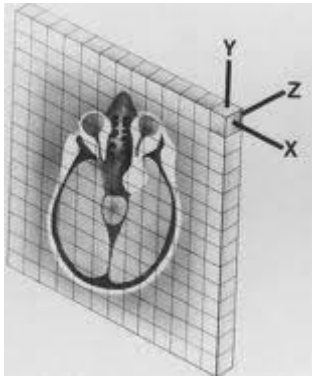




Factors affecting Time of flight phenomenon:

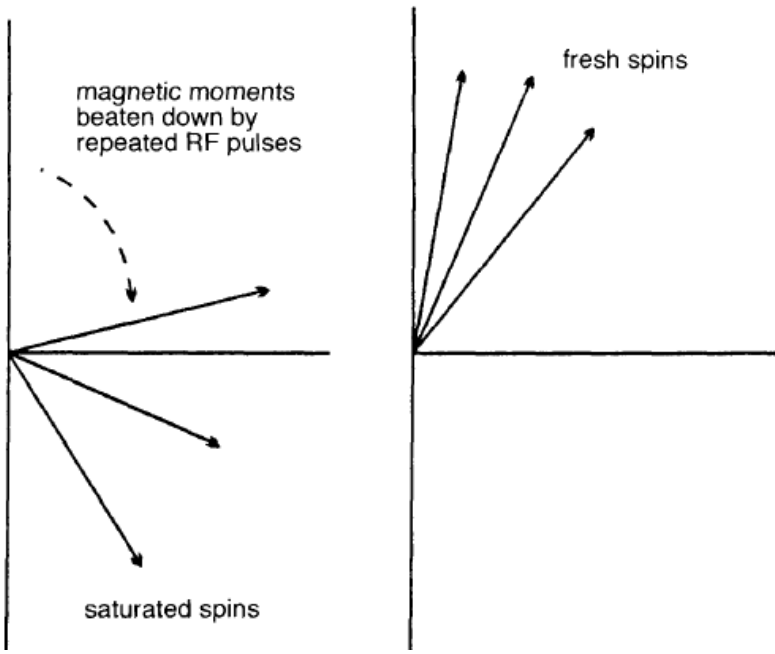
(4) Slice thickness

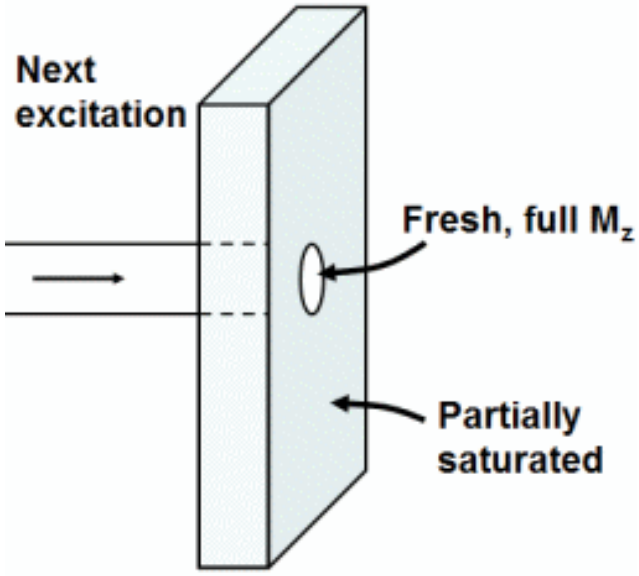
- Nuclei take longer to travel through a thick slice compared with a thin slice → nuclei are more likely to receive both the 90^{o} and 180^{o} pulse in thick slices.
- As the thickness of the slice decreases, the nuclei are more likely to receive only one pulse and the signal void increases.



Entry slice phenomenon (in-flow effect)

- Stationary nuclei which receive repeated RF pulses during the acquisition are said to be saturated or 'beaten down‘.
- Nuclei flowing perpendicular to the slice enter the slice fresh, as they were not present during repeated excitations. They therefore produce a different signal from the stationary nuclei. This is called *entry slice phenomenon or in-flow effect*
- Occur more with gradient echo pulse sequences as the normal tissues will be more saturated due to low TR

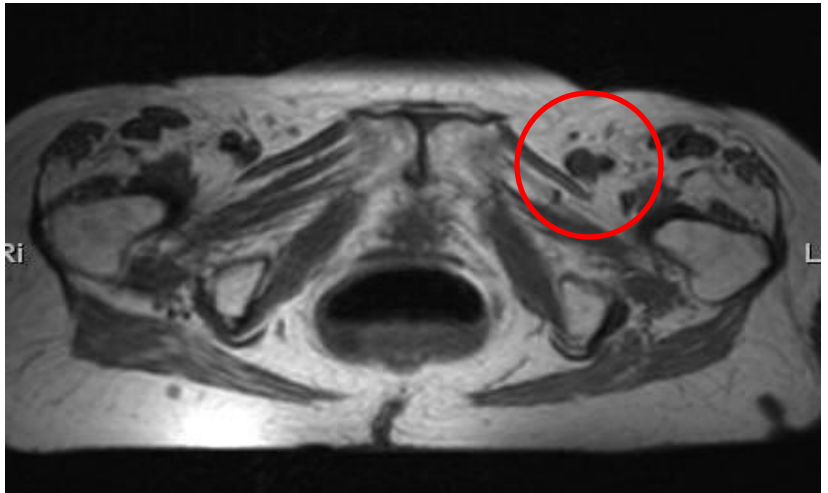




Factors affecting entry slice phenomenon

1) Order of the slice:

- This effect is most prominent in the first slice of a 'stack' of slices.
- The slices in the middle of the stack exhibit less entry slice phenomenon, as flowing nuclei have received more excitation pulses by the time they reach these slices (become less fresh and more saturated)



Factors affecting entry slice phenomenon

2) TR:

- Short TR results in an increase in the rate at which the RF is delivered.
- A very short TR therefore reduces the magnitude of entry slice phenomena.

3) Slice thickness:

- Flowing nuclei with a constant velocity take longer to travel through thick slices than thin slices.
- Nuclei travelling through thick slices are likely to receive more RF pulses than nuclei travelling through thin slices.
- Entry slice phenomenon therefore increases in thin slices compared with thick slices.

Factors affecting entry slice phenomenon

4) velocity of flow:

- Fast flowing nuclei are more likely to have travelled to the next slice when RF is delivered than slow nuclei.
- Entry slice phenomenon is therefore increased as the velocity of flow increases.

Factors affecting entry slice phenomenon

5) direction of flow:

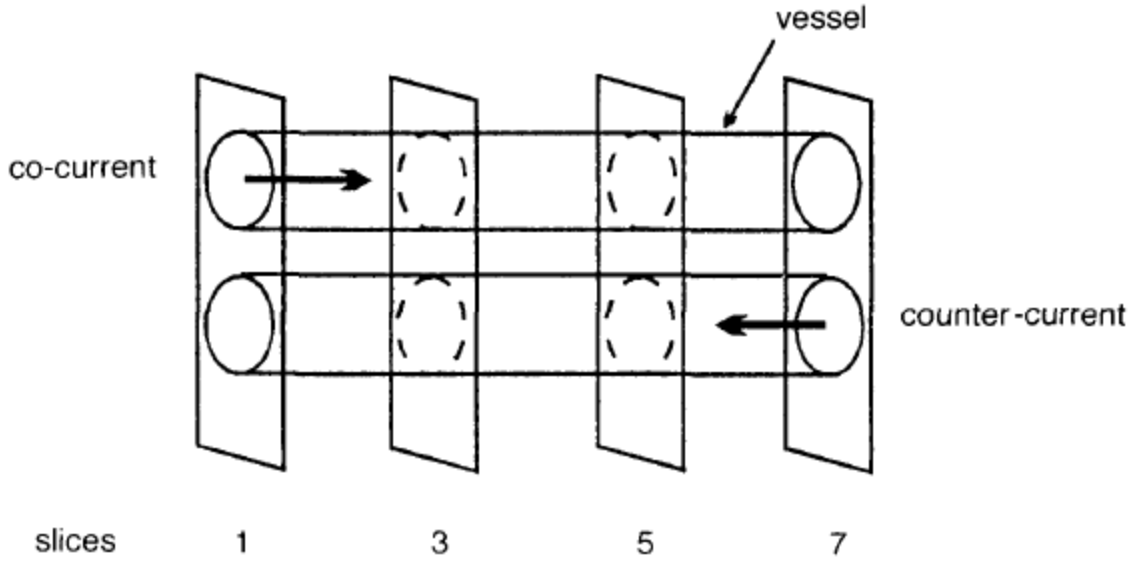
- the most important factor in determining the magnitude of entry slice phenomenon.

Co-current flow

- Flowing nuclei travel in the same direction as slice selection.
- The flowing nuclei are more likely to receive repeated RF excitations as they move from one slice to the next→become saturated relatively quickly, and so entry slice phenomenon decreases rapidly.

Counter-current flow

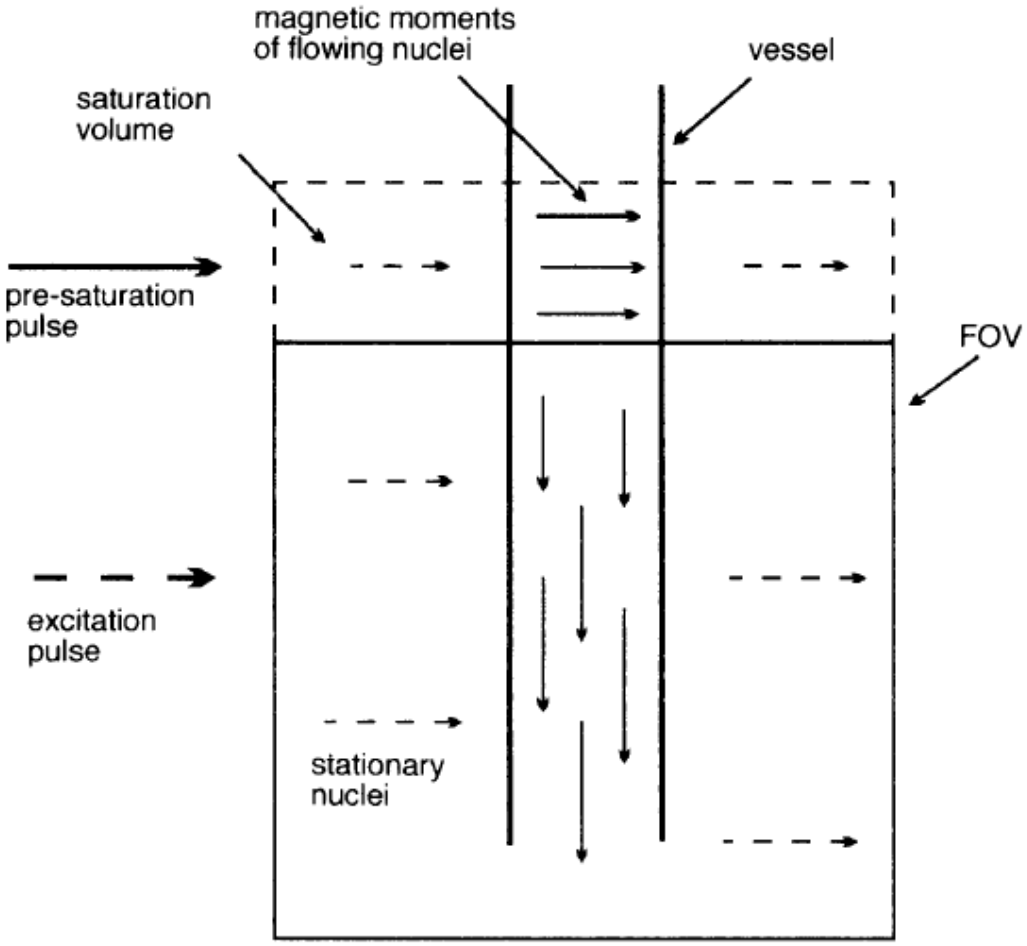
- Flowing nuclei travel in the opposite direction to slice excitation.
- Flowing nuclei stay fresh as when they enter a slice they are less likely to have received previous excitation pulses.
- Entry slice phenomenon does not therefore decrease rapidly and may still be present deep within the slice stack



Compensation of entry slice phenomenon

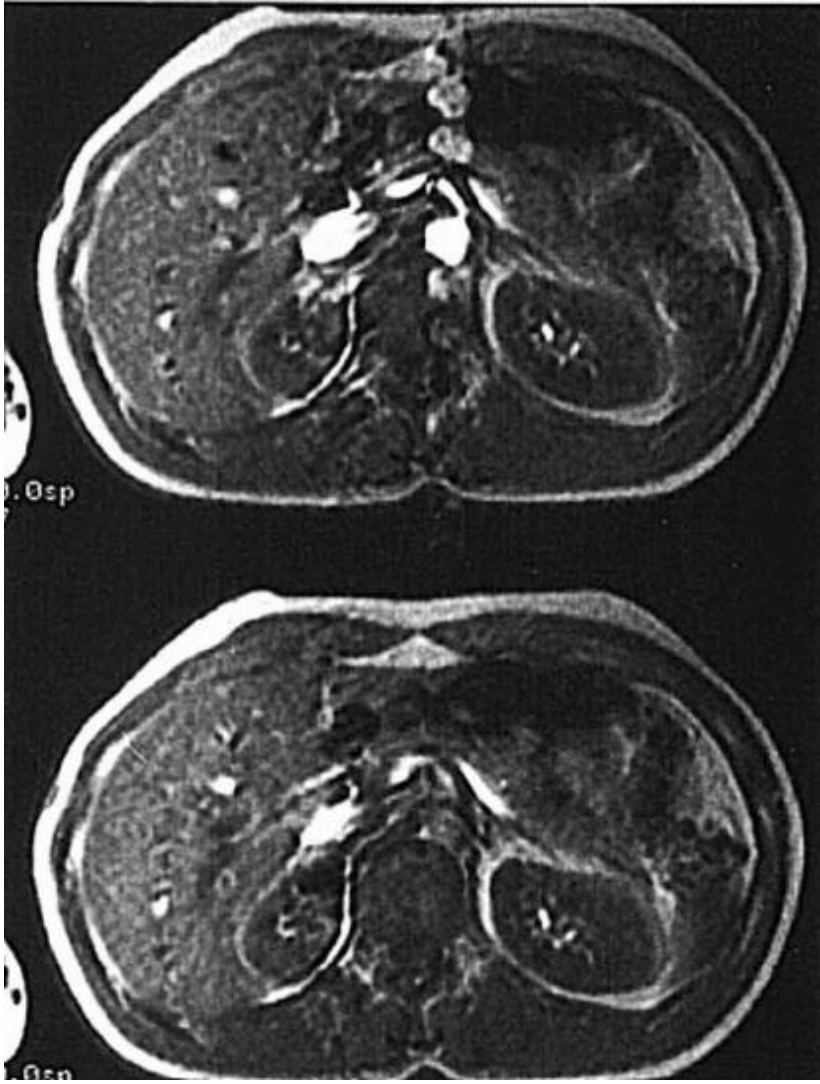
Pre-saturation

- Pre-saturation pulses nullify the signal from flowing nuclei → minimize effects of entry slice and time of flight phenomena (flow related enhancement).
- Presaturation delivers a 90° RF pulse to a volume of tissue outside the FOV →A flowing nucleus within this volume receives 90° pulse.
- When it then enters the slice stack, it receives an excitation pulse and is saturated. (has no transverse component of magnetisation)→ produces a signal void.
- In axial imaging: pre-saturation pulses are placed above and below the FOV so that arterial flow from above, and venous flow from below is saturated.



Disadvantages:

- Pre-saturation pulses are only useful if applied to tissue (If applied to air they are not effective).
- Increase the amount of RF that is delivered to the patient, which may increase heating effects
- The use of pre-saturation pulses may decrease the number of slices available



Other uses of pre-saturation

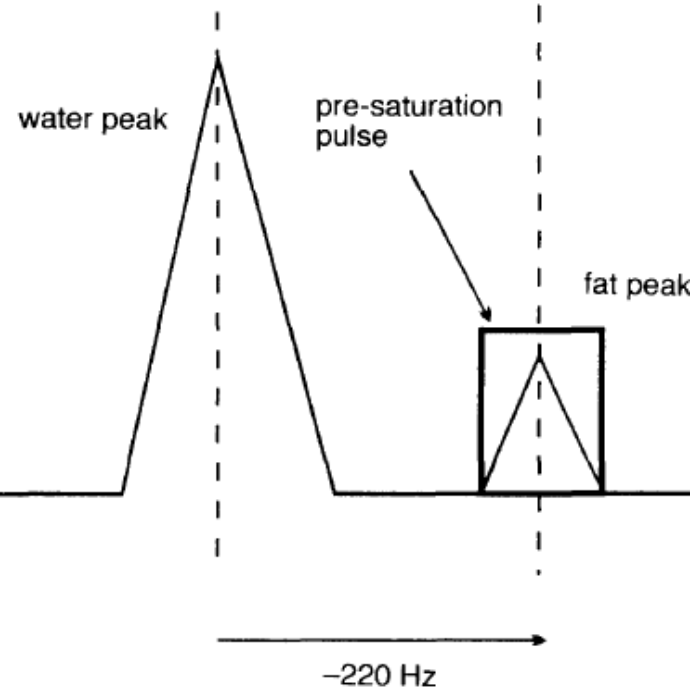
(1) Fat saturation,

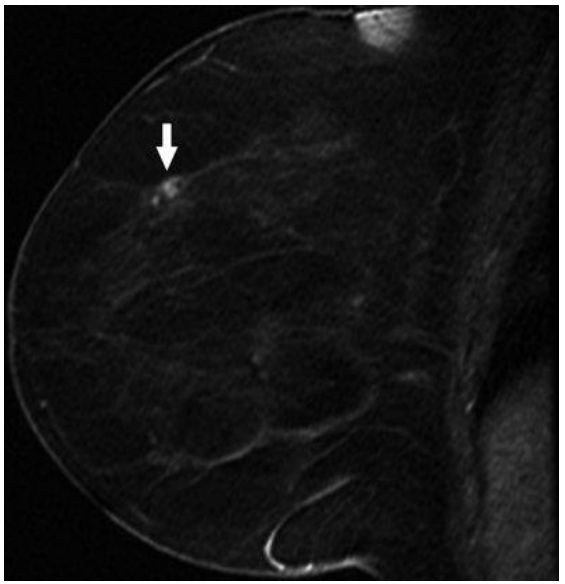
(2) to reduce aliasing (see later)

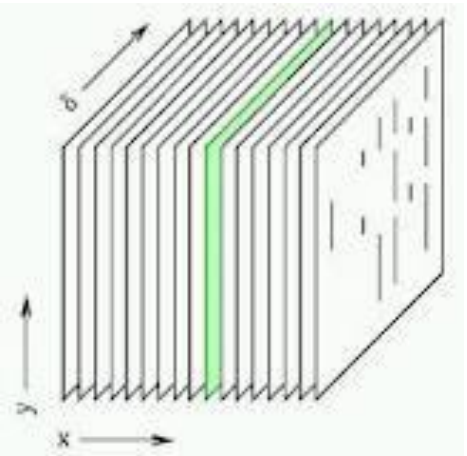
Fat saturation:

- The precessional frequency of fat is slightly different from that of water (why?).
- As Bo strength ↑ →frequency difference between fat & water also ↑
- In order to saturate either fat or water, the precessional difference between the two must be sufficiently large to be isolated from each other→ Fat or water saturation is most effective in high field systems.

- To saturate fat signal, a 90° pre-saturation pulse must be applied at the precessional frequency of fat to the whole FOV
- The excitation RF pulse is then applied to the slices and the magnetic moments of the fat nuclei are flipped into saturation (180°) →no transverse magnetisation → become signal void.
- Always used with post contrast studies
- The interval between the pre-saturation pulses is called the SAT TR = scan TR / number of slices.





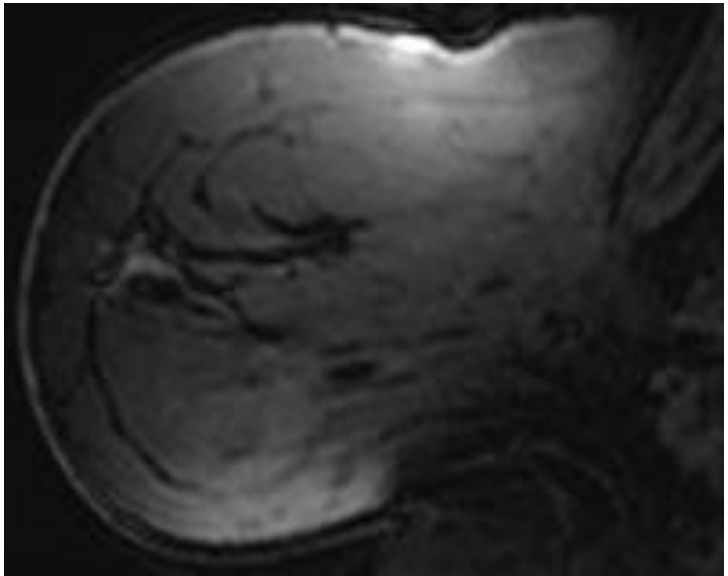


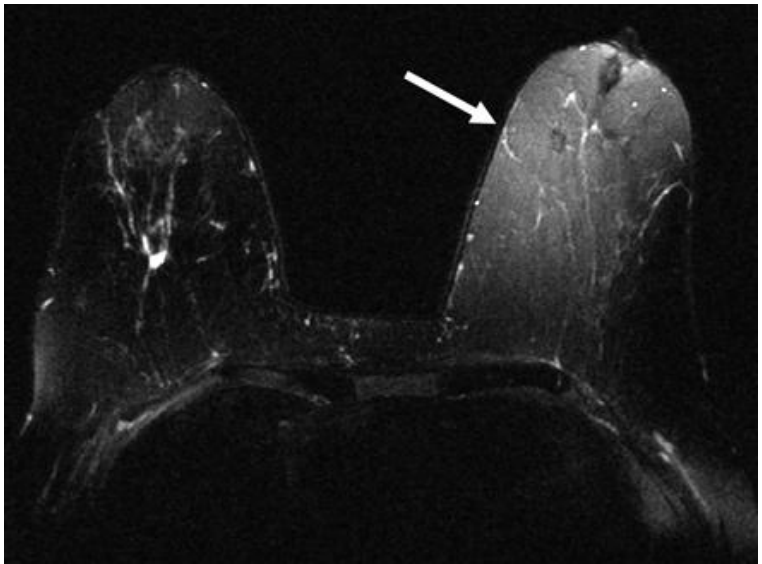
Disadvantages:

1) Inhomogeneous fat suppression due to

– A particularly dense area of fat receives the same pre-saturation energy as an area with very little fat. →fat saturation is less effective.

– The gradients applied for spatial encoding vary the frequency across each slice → pre-saturation often appears non-uniform across the slice , with optimal saturation occurs at the centre of a slice





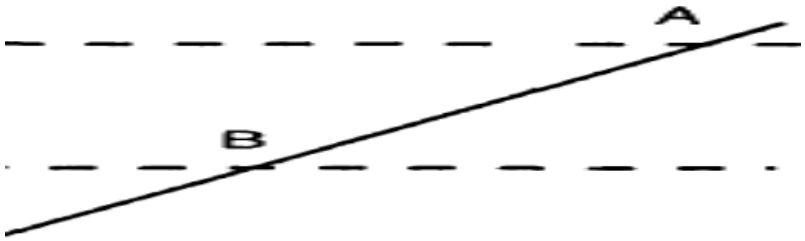
2) Delivers extra RF into the patient

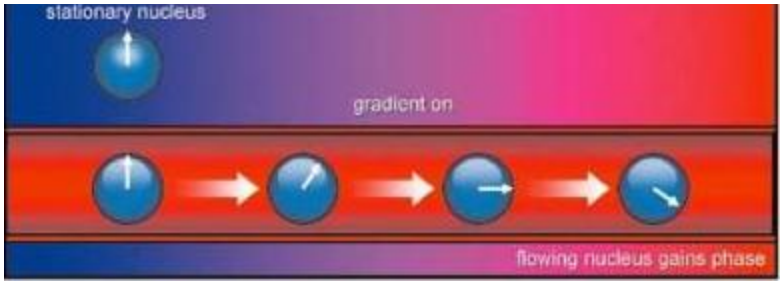
3) Reduces the number of slices available for a given TR.

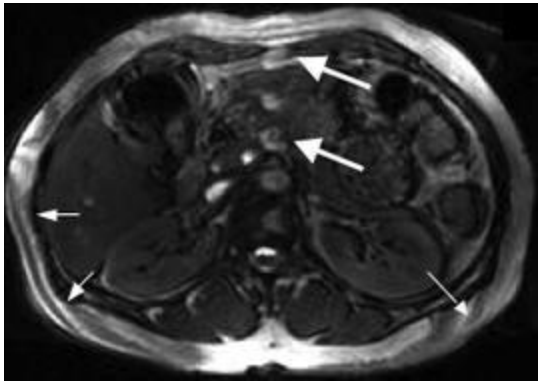
4) If SAT TR is longer than the T1 times of fat →the NMV's of fat may not be saturated (have time to recover before each pre-saturation pulse is delivered). To prevent this, always prescribe the maximum number of slices available for a given TR so that the SAT TR is reduced to a minimum.

Intra-voxel dephasing

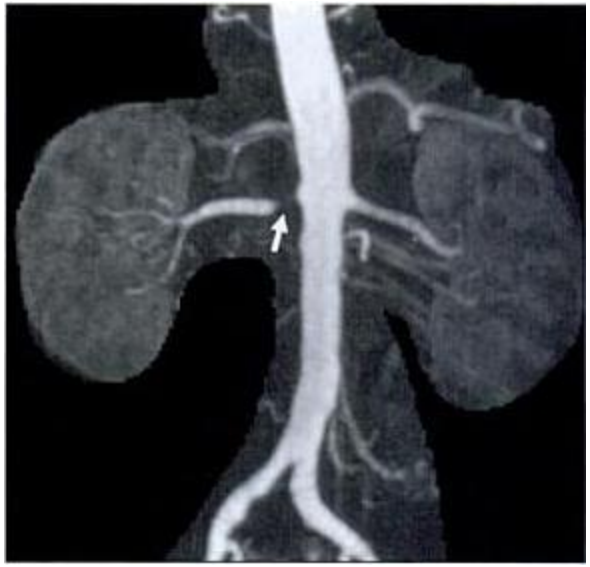
- Nuclei flowing along a gradient rapidly accelerate or decelerate depending on the direction of flow and gradient application.
- Flowing nuclei therefore either gain phase (if they have been accelerated), or lose phase (if they have been decelerated).
- If a flowing nucleus is adjacent to a stationary nucleus in a voxel, there is a phase difference between the two nuclei → nuclei within the same voxel are out of phase
- Results:
  - Reduction of total signal amplitude from the voxel (*intra-voxel dephasing)*
  - Aorta ghosting







- The magnitude of intra-voxel dephasing depends on the degree of turbulence.
  - **In turbulent flow, intra-voxel dephasing effects are** irreversible.
  - **In laminar flow, the intra-voxel dephasing can be compensated** for as long as the velocity of flow is constant.



Intra-voxel dephasing compensation

1) Even echo rephasing:

- If two or more echoes are produced in a spin echo pulse sequence, intravoxel dephasing may be reduced by acquiring the second and succeeding even echoes
- Explanation:
  - Flowing nuclei that are out of phase at the first echo, are in phase at the second echo as long as the nuclei are given exactly the same amount of time to rephase as they were given to dephase.

2) Gradient moment rephasing (nulling)

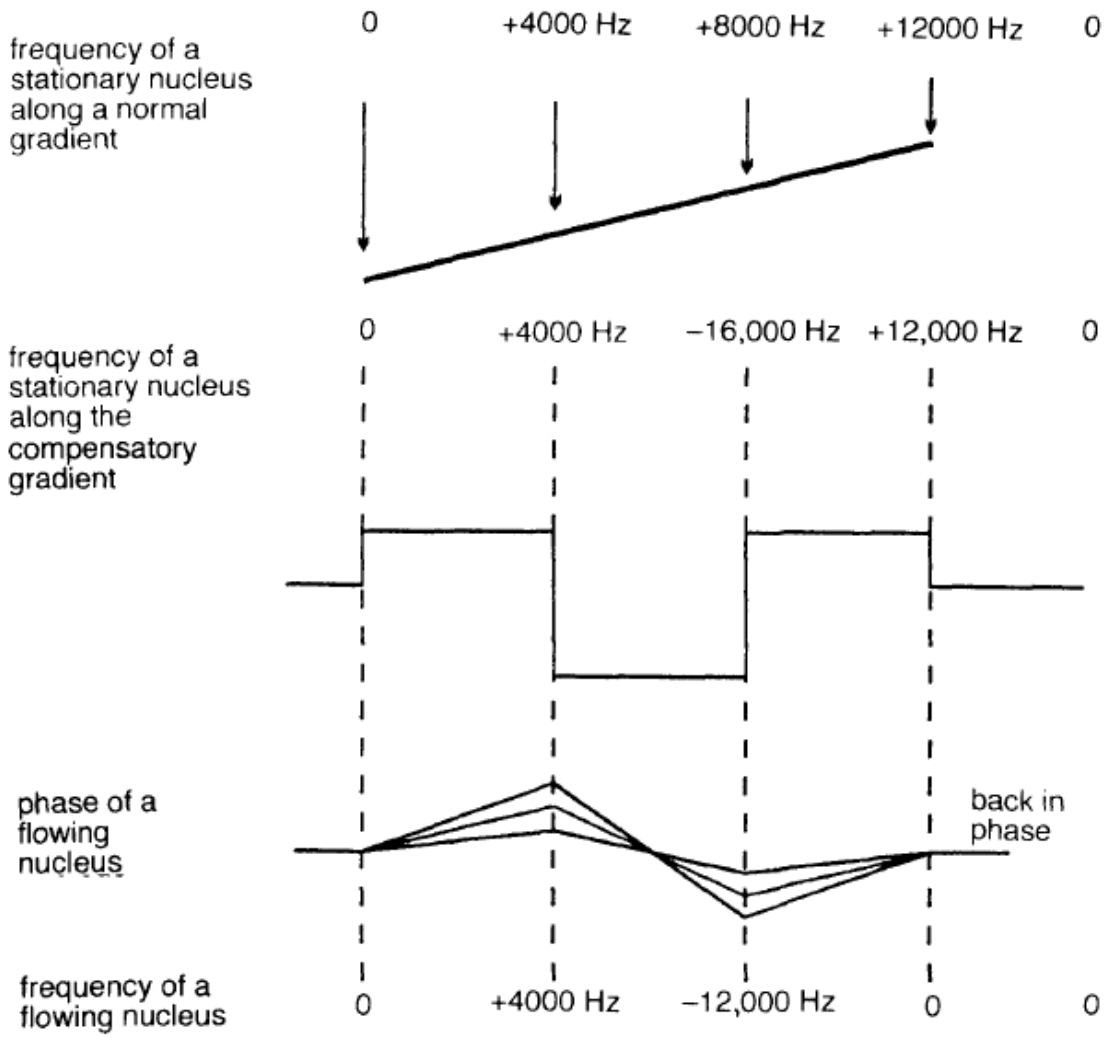
Idea:

Use of additional gradients to correct the altered phases back to their original values→ flowing nuclei do not gain or lose phase due to the presence of the main gradient.

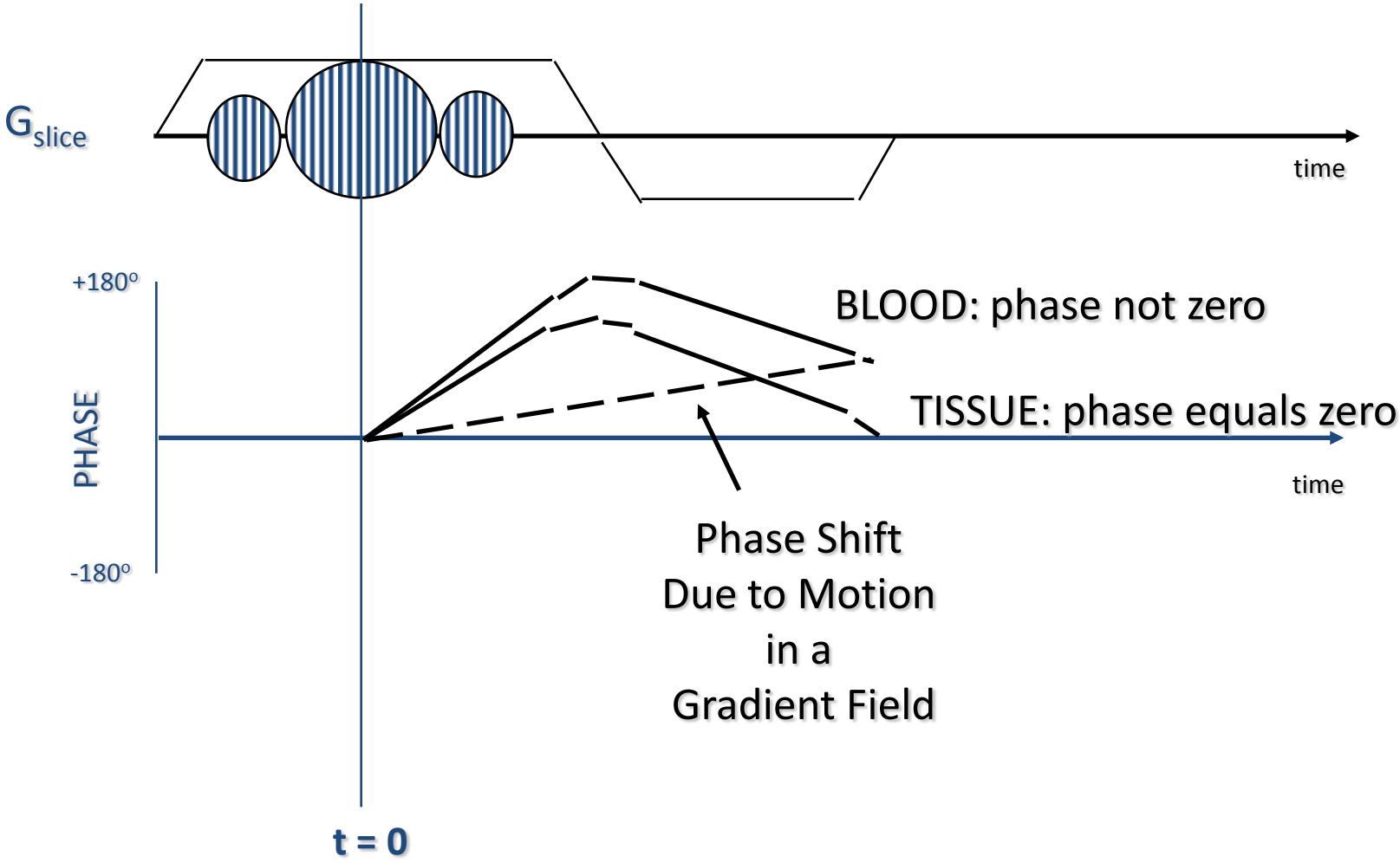
performed by the slice select gradient and/or the readout gradient.

Mechanism:

- The gradient alters its polarity from positive to double negative and then back to positive again.
- A flowing nucleus travelling along these gradients, experiences different magnetic field strengths. Therefore its precessional frequency changes accordingly.
- the precessional frequency at the beginning of gradient moment rephasing will be the same as it is at the end→ The net precessional frequency and phase change =zero



Summary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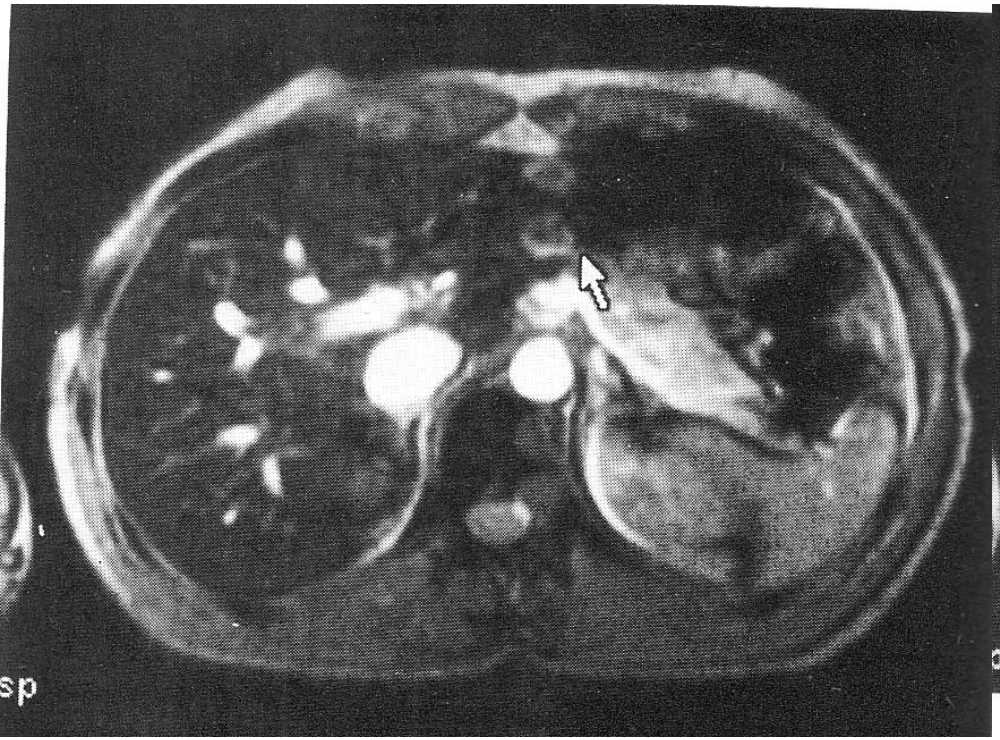
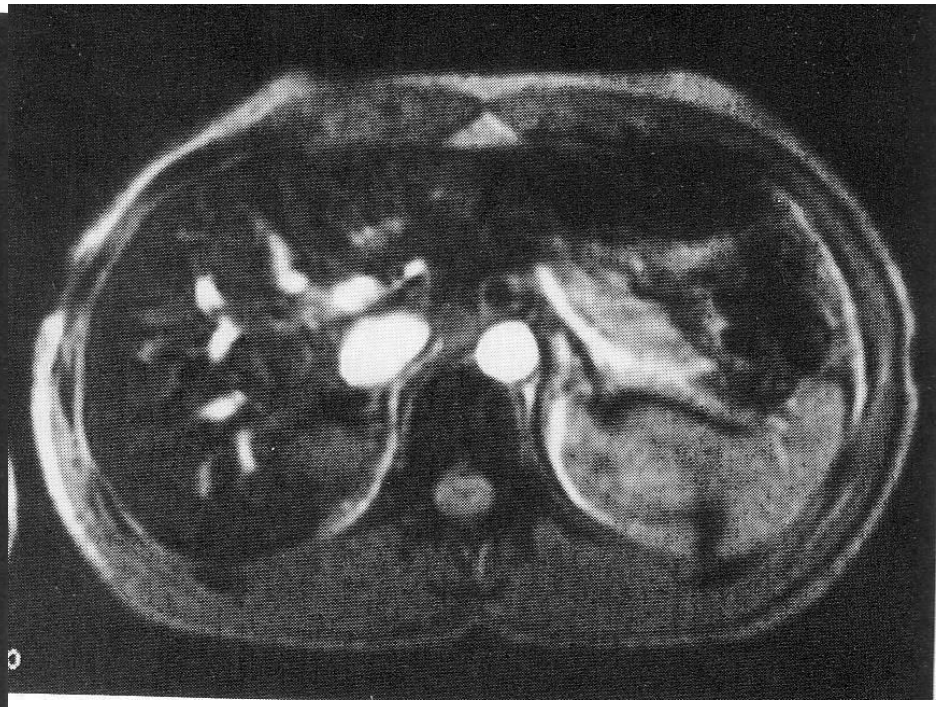
+180°
PHASE
-180°
BLOOD: phase not zero
TISSUE: phase equals zero
time
Phase Shift
Due to Motion
in a
Gradient Field
t = 0

Example





Without GMR – shows mismapping of the flowing nuclei within the aorta (arrow)

With GMR

Disadvantages:

- Gradient moment rephasing assumes a constant flow velocity across the gradients at all times →most effective on slow laminar flow (first order motion compensation)
- Pulsatile flow is not strictly constant so gradient moment rephasing is often more effective on venous rather than arterial flow.
- It is also less effective on turbulent , fast flow perpendicular to the slice.
- As gradient moment rephasing uses extra gradients , it increases the minimum TE and fewer slices may be available for a given TR.

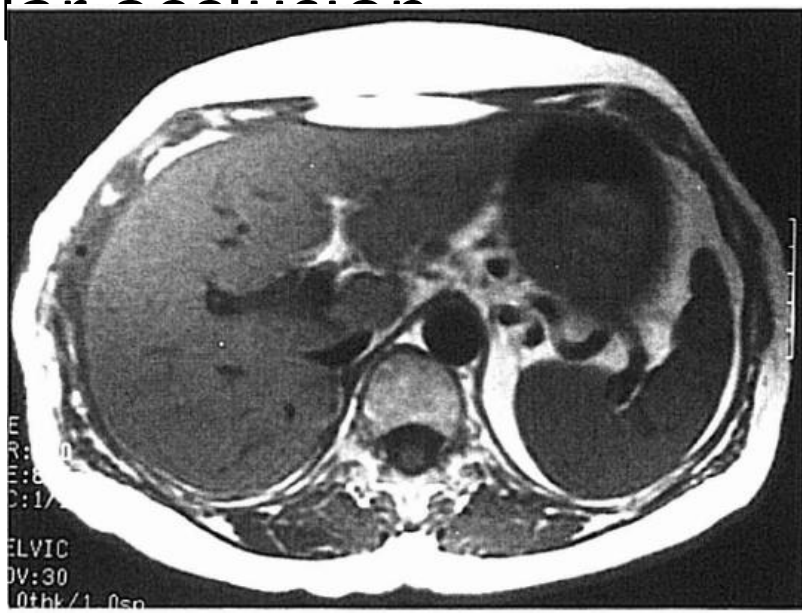
As flowing nuclei are bright when gradient moment rephasing is selected, it is usually used in T2 and T2* weighted sequences where fluid is bright anyway.

MRA

Conventional vascular imaging techniques

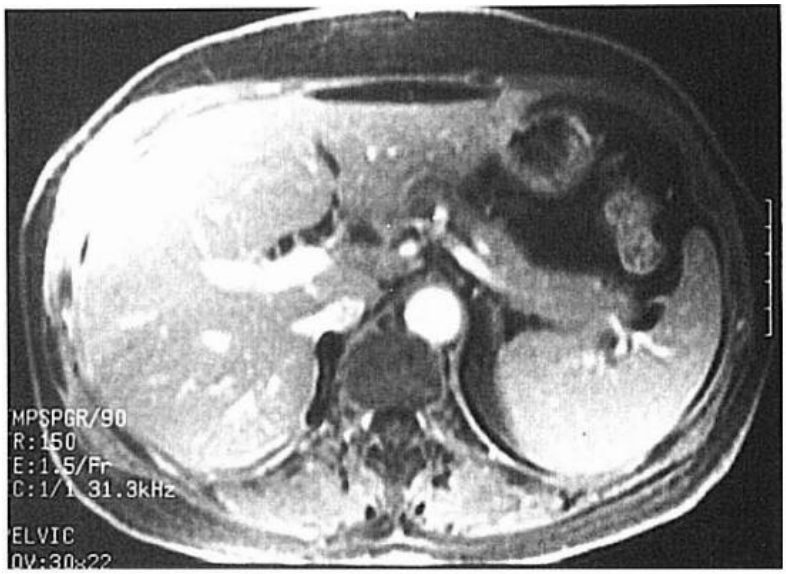
Black blood imaging:

- Techniques employed to produce images where vessels appear dark. These include
  - Spin echo acquisitions
  - Application of pre-saturation pulses.
- Persistent signal within vessel lumen indicates either slow flow, clot or vascular occlusion



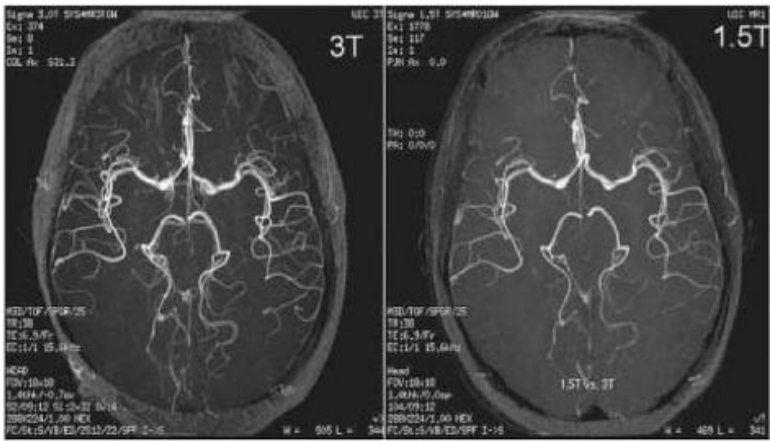
Bright blood imaging

- Techniques used to enhance the signal from flowing blood:
  - Gradient echo imaging
  - Gradient moment rephasing
  - Contrast enhancement.
- Absent signal within vessel lumen indicates either slow flow, clot or vascular occlusion.



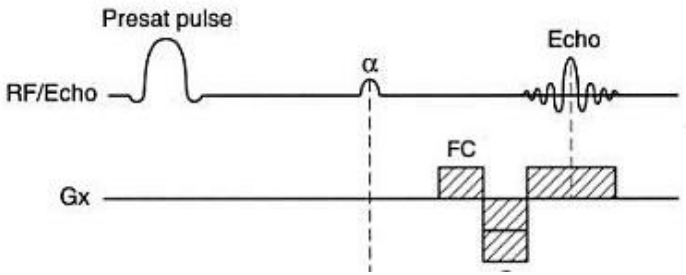
Time Of Flight (TOF) MRA

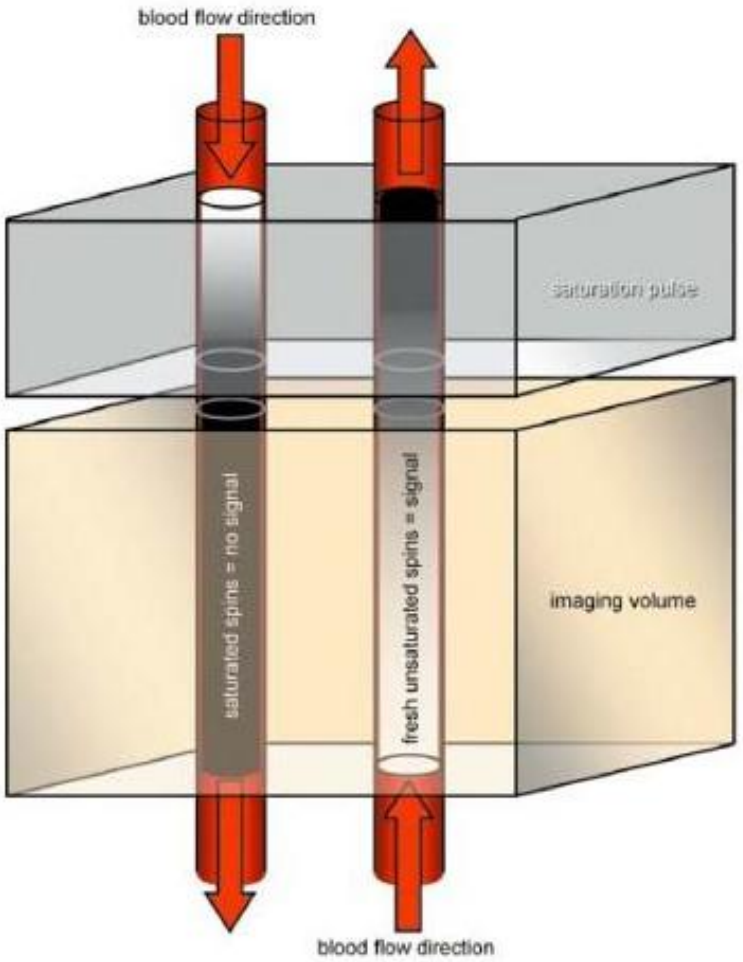
- TOF-MRA uses the following:
  1) Incoherent gradient echo pulse sequence
     - TR is kept below the T1 time of the stationary tissues so that T1 recovery is prevented. This beats down the stationary spins and inflow effect from fresh flowing spins produces high vascular signal.
     - A flip angle of 45-60° in conjunction with a TR of 40-50 ms, is usually sufficient to maximize signal without suppressing the signal from flowing nuclei.
     - Within this flip angle and TR range, saturation of flowing spins only occurs at flow velocities less than 3 cm/s
     - If the TR is too short, most of flowing spins may be suppressed along with the stationary spins which reduces vascular contrast.
  2) + gradient moment rephasing:
     - Enhance flow.
  3) +/- Contrast agents:
     - Shortening T1 times of flowing spins → Signal intensities are increased



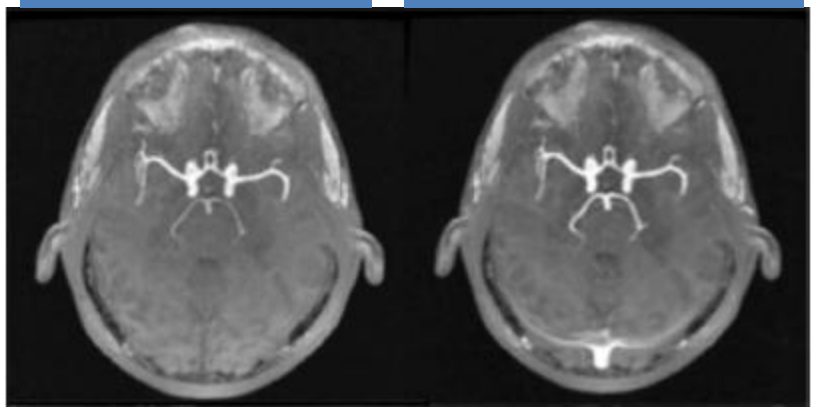
NOTE:

- TOF-MRA can be acquired in 2D or 3D acquisition.
- To evaluate signals from arterial flow, saturation pulses is applied in the direction of venous flow.
  - e.g. to evaluate the carotid arteries in the neck, apply saturation pulses superior to the imaging volume to saturate the signal from inflowing venous blood





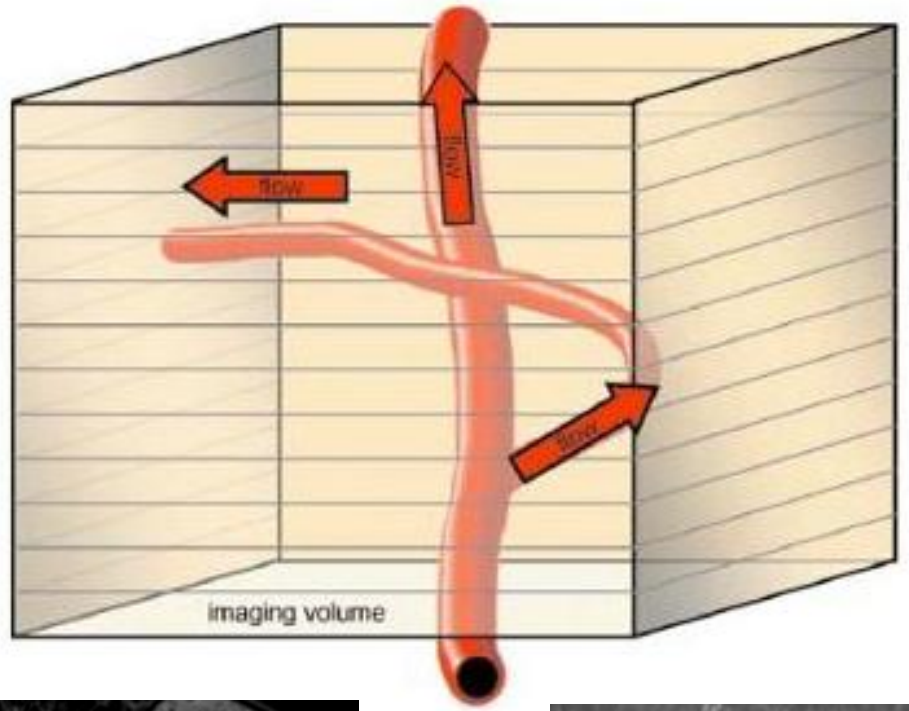
With pre-saturation | Without pre-saturation

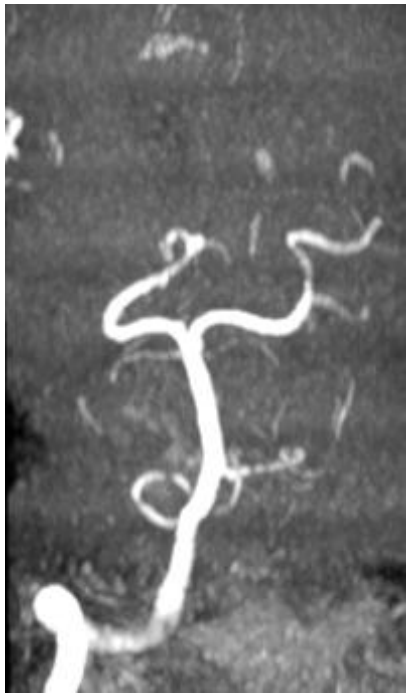


Disadvantages

1) Saturation of in-plane flow (any flow within the FOV) along with background tissue.

TOF-MRA is mostly sensitive to flow that comes perpendicularly into the FOV and the slice.





Disadvantages

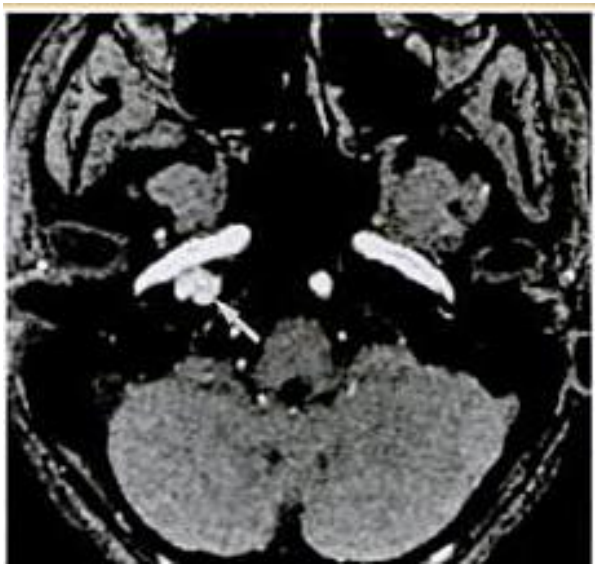
2)High signal in some background tissues.

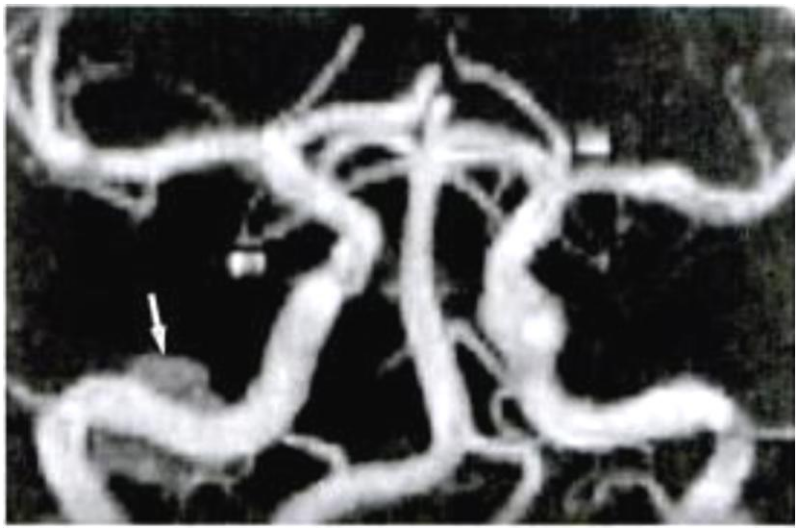
- TOF is acquired with an incoherent gradient echo sequence (T1) → tissues with short T1 times appear bright.
- As a result of this phenomenon, high signal intensity can be seen presence of

  1) methaemaglobin→ there is a problem in distinguishing sub-acute haemorrhage from flowing blood on TOF-MRA images.

  2) fat.

  - This can be minimized by
    - Choosing a certain TE → protons from fat and water are out of phase with each other, and therefore cancel each other out.
      - » The TE should however be kept relatively short, to minimize phase ghosting and susceptibility artefacts
    - Magnetisation transfer coherence (MTC) techniques addition



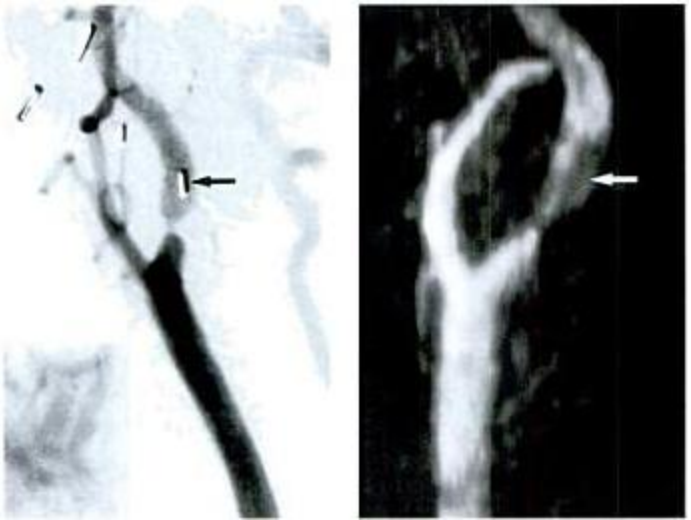


Disadvantages

3)Susceptibility artifacts that are present on any gradient echo sequence, including TOF-MRA:

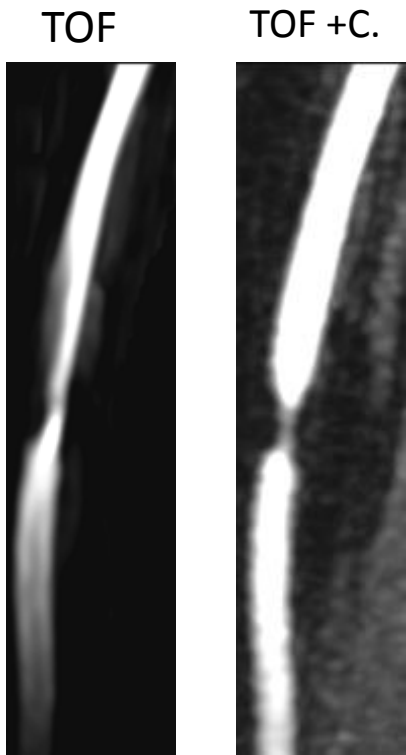
Compensated by using:

- Shorter TEs: does not permit time for dephasing and therefore a TE of less than 4 ms minimizes this artifact.
- Smaller voxel: →less intra-voxel dephasing and therefore small FOVs, thin slices and fine matrices will reduce this effect (see later)



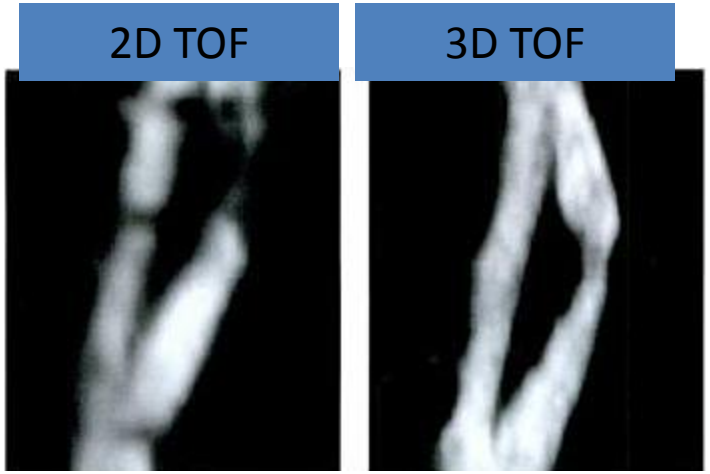
TOF-MRA advantages

- Sensitive to T1 effects and contrast may be given for additional enhancement.
- Reasonable imaging times (approximately 5 min depending on parameters).
- Sensitive to slow flow.
- Reduced sensitivity to intra-voxel dephasing.



2D *versus 3D TOF-MRA*

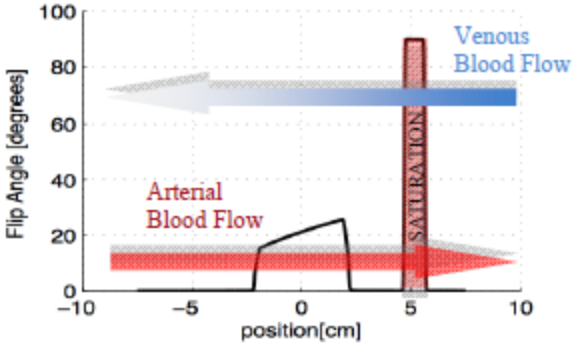
- Advantages of 3D over 2D TOF:
  1. Offers high SNR
  2. Thin contiguous slices for good resolution



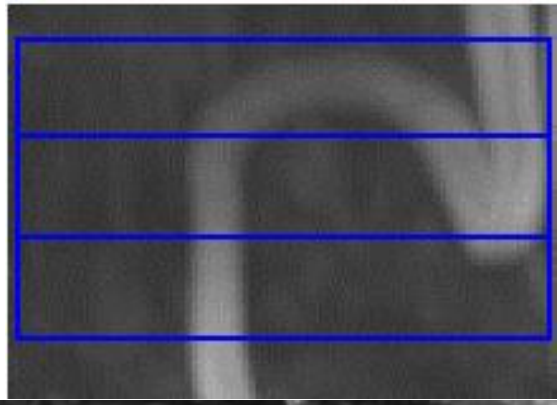
- Advantages of 2D over 3D TOF:
  1. 3D acquisition shows higher risk of saturating of in-plane flow signals.

     Overcome by:

     - Ramped RF pulses: flip angle increases across the volume of the slab. → signal from spins that have flowed across the volume of tissue still produce signal at the end of the imaging volume.
     - Administration of intravenous contrast agents
     - Use 2D whenever slow flow is suspected
     - 3D TOF should be used in areas of high velocity flow (intra-cranial application)



- Advantages of 2D over 3D TOF:



2. 3D offer small area of coverage due to higher probability of saturation of flow

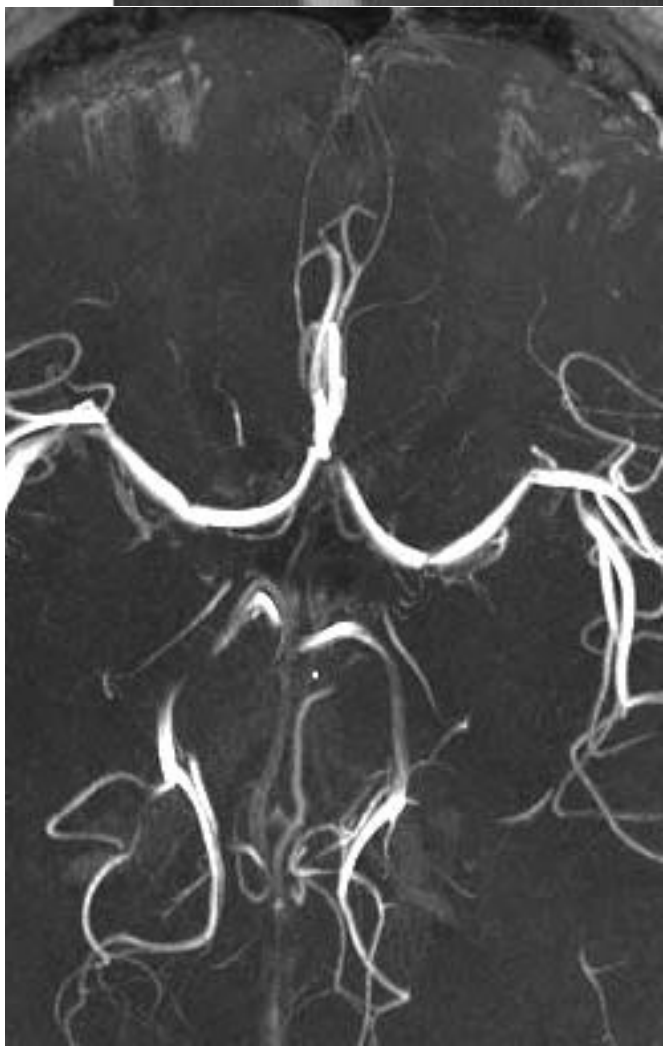
   Overcome by:

   •MOTSA (Multiple Overlapping Thin Section Angiography):

   - ➢It combines a number of high resolution 3D acquisitions to produce an image that has good resolution and a large area of coverage.
   - ➢Combines advantages of 2D and 3D TOF
   - ➢Disadvantage: Venetian blind artefact (incorrect matching of separate volumes due to gross patient motion and signal variation at the volume boundries because of residual saturation effects

   •Acquire images in the plane that best covers the anatomy. E.g. ascending and descending aortic arch in sagittal plane , renal arteries in coronal plane

   •Use 2D in large coverage



- **Parameters for TOF-MRA:**

(1) TR 45 ms

(2) Minimum allowable TE

(3) Flip angles approximately 60°.

- The selection of a short TR and medium flip angles allows for saturation of stationary nuclei but the moving spins coming into the slice remain fresh, and so vascular image contrast is maximised.
- The short TE reduces phase ghosting and susceptibility artifacts found on gradient echo.

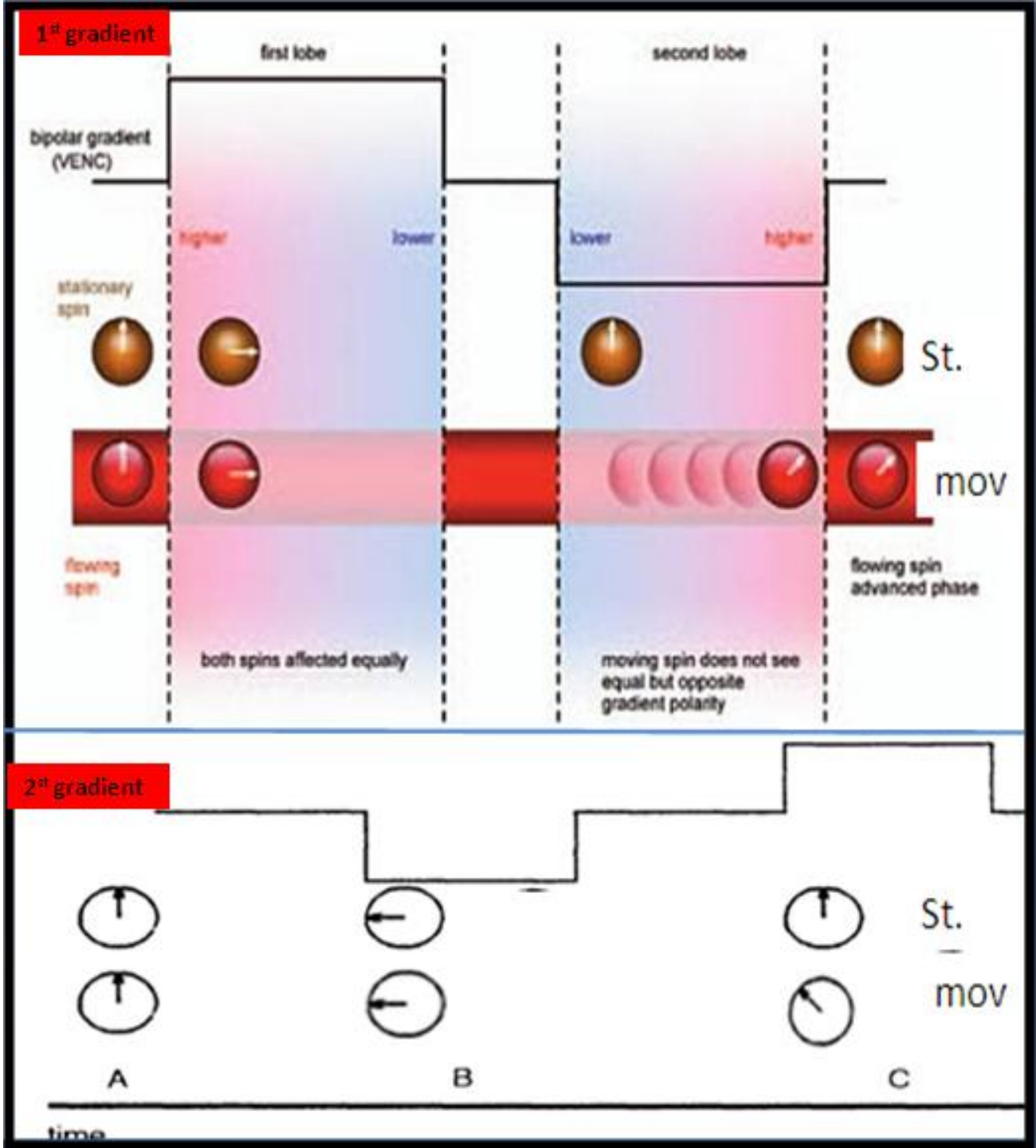
Phase contrast (PC) MRA

Definition:

- Phase contrast MRA utilizes phase shifts which are introduced selectively for moving spins by phase encoding the velocity of flow with the use of a bipolar gradient.

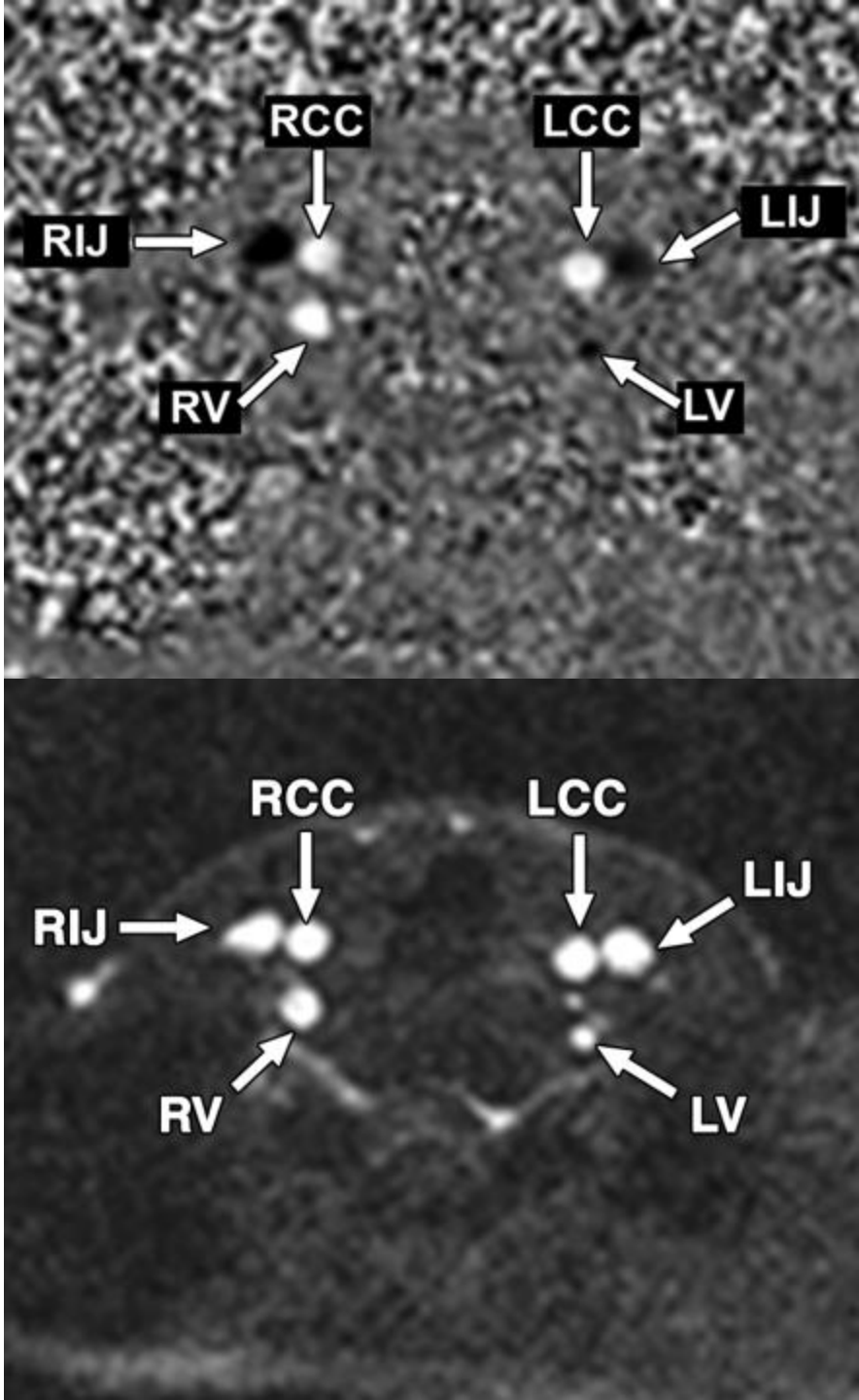
Technique:

- A bipolar gradient is applied :
  - At first part of initial bipolar gradient , there is a shift of phases of stationary spins and flowing spins.
  - After the second part of the first bipolar gradient*, the stationary spins return to their* initial phase, but those of moving spins acquire some phase.
  - The bipolar gradient is then applied with opposite polarity but at the same strength so that the same variations occur, but in the opposite direction.
  - Both images are then subtracted



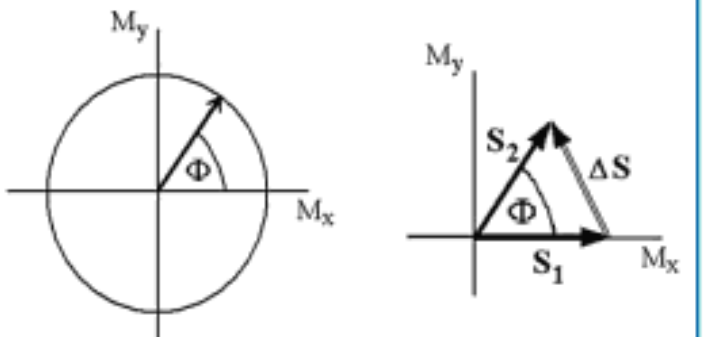
Two types of images can be formed:

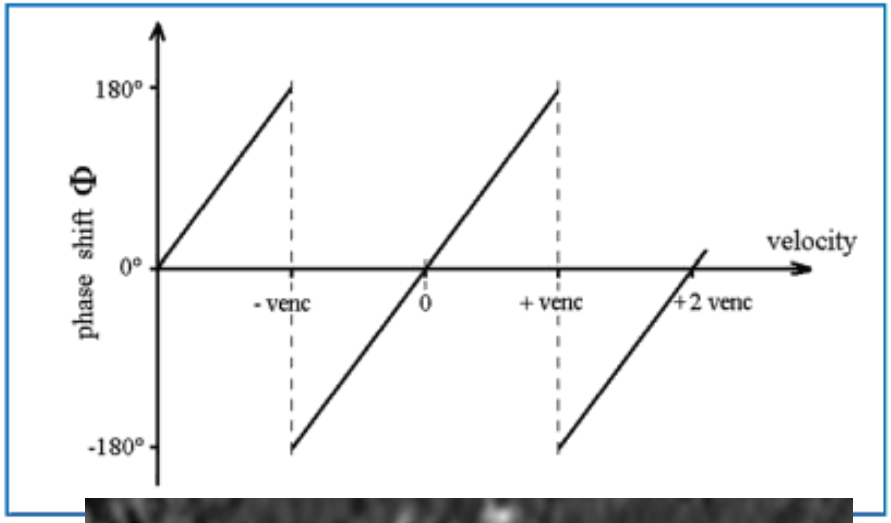
- **Phase images:**
  - phase difference in depicted as signal intensity
  - Non moving spins appear as a medium shade of gray, while moving blood is either brighter or darker according to direction of flow (intensity difference from stationary nuclei is proportional to velocity)
- **Magnitude images:**
  - Background tissues are suppressed
  - Brightness of each pixel is a measure of velocity
  - No information about direction of flow

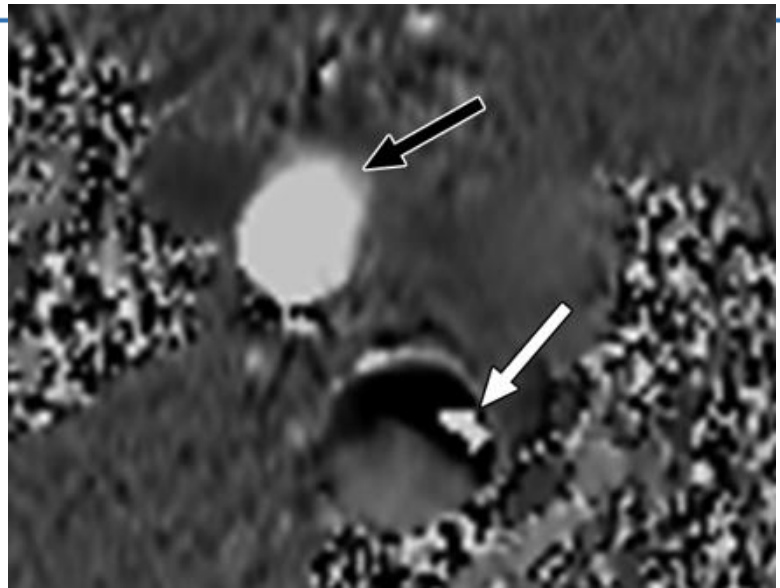


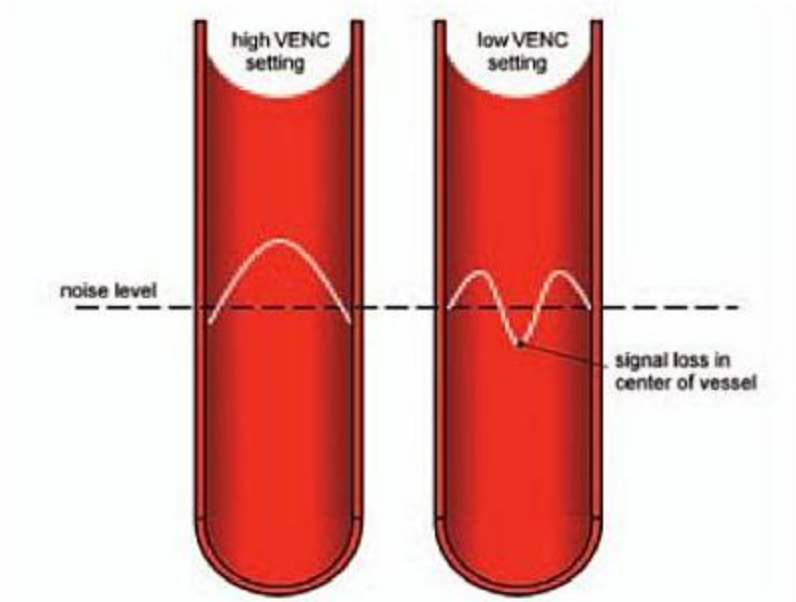
Velocity encoding (VENC):

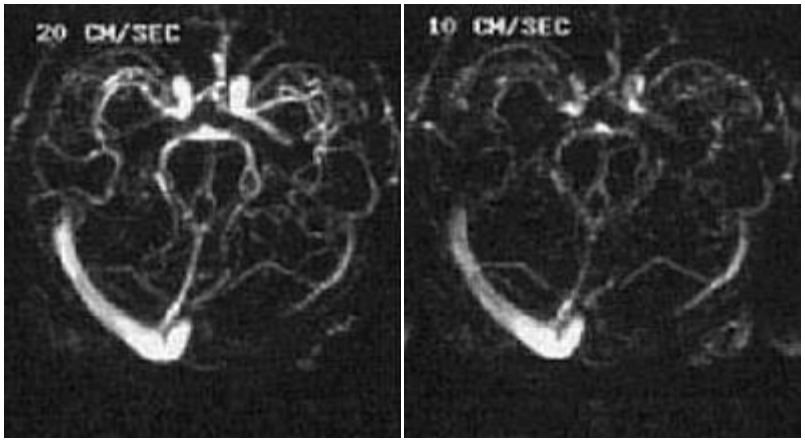
- Critical velocity at which the difference in phase reach 180°
- Determined by the strength of the bipolar flow encoding gradients
- If velocity exceeds VENC value →abrupt change of signal from bright to dark (or vice versa) = aliasing
- Example: VENC= 40 cm/sec:
  - Flow of 40 cm/sec produce 180° phase shift and maximum signal
  - Flow of 80cm/sec produce no signal
- In clinical practice it is important to estimate the maximum flow velocity expected to avoid aliasing







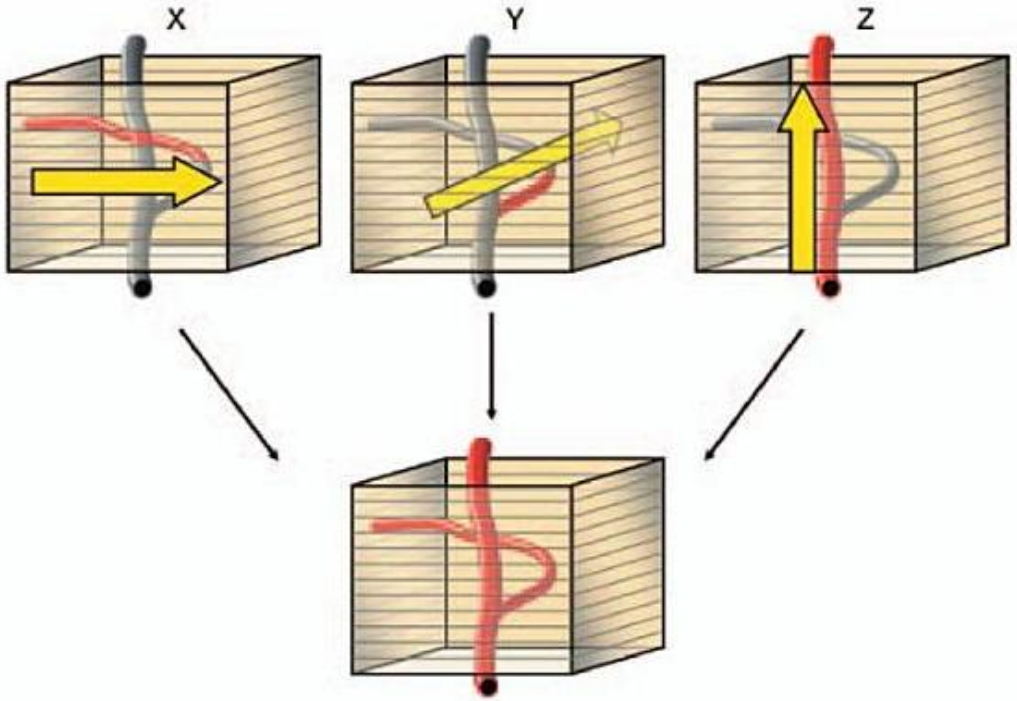


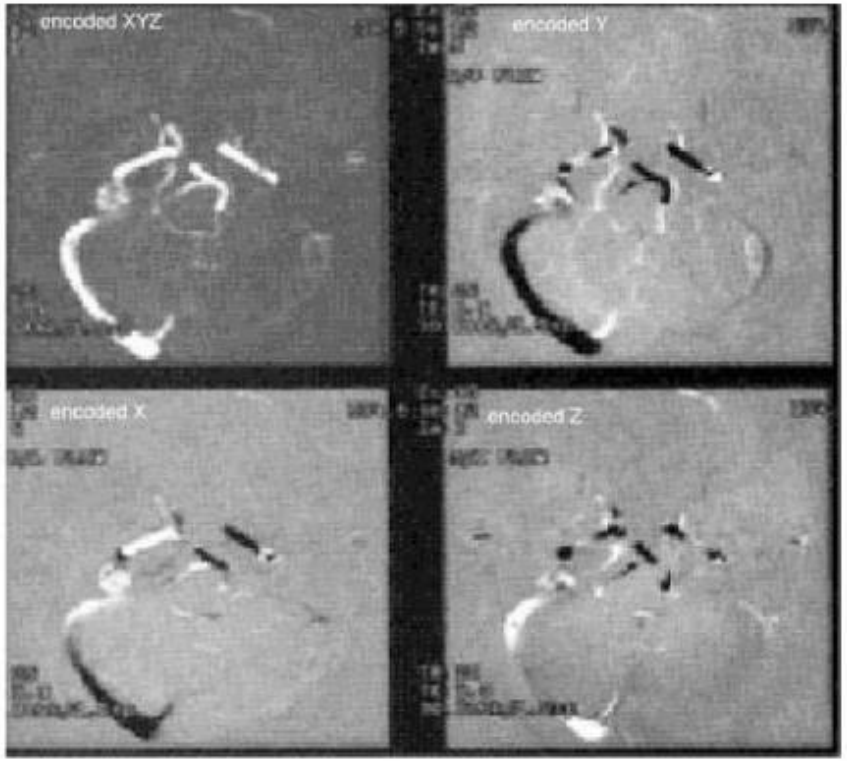


Aliasing occur at center of fast flowing vessels (laminar flow)

Flow encoding axes

- Sensitisation to flow is obtained along the direction of the applied bipolar gradient.
- If the bipolar gradient pulses are applied along the Z-axis, phase shifts are induced in flow that occurs along this axis, (sensitive to flow which runs from head to foot).
- Since flow can occur in other directions, bipolar gradients are applied in all three dimensions → sensitize flow in all three directions X, Y, and Z
- These are known as flow encoding axes.
- However, an increase in the number of flow encoding axes also increases the imaging time.





N.B.

- Contrast agents can improve the signal in PC-MRA.
- Examples of VENCs:

Vessel	Flow velocity (cm/s)
Ascending aorta	50 – 100
Descending aorta	100
Aortic stenosis	150 – 500
Aortic valve insufficiency	150 – 200
Common carotid artery	60 – 80
Carotid artery stenosis	100 – 500
Middle cerebral artery	60
Basilar artery	40 – 50
Femoral artery	60 – 80
Popliteal artery	35 – 40
Vena cava	5 – 40
Portal vein	5 – 10

- Clinical applications of MRA techniques:

	3D-TOF	2D-TOF	3D-PC	2D-PC	Magnitude contrast	CE MRA
Intracranial:						
- Arteries	***		*			*
- Veins	*	***	**	*		*
Carotids	**	**				***
Peripheral vessels		**			*	***

*** method of choice; ** second-best alternative or for additional information; * working technique, but with sub-optimal results

2D *and 3D PC-MRA:*

2D PC-MRA:

Advantages:

- provide acceptable imaging times (1 to 3 min)

Disadvantages:

- Sometimes cannot be reformatted and viewed in other imaging planes.

3D PC-MRA:

Advantages:

- Better SNR
- Better spatial resolution
- Ability to reformat in a number of imaging planes retrospectively.

Disadvantages:

- imaging time increases (scan times can approach 15 min or more)

Advantages of PC-MRA over TOF -MRA

- Excellent background suppression
- Enables quantitative flow measurements
- Information about the flow direction
- No saturation to slow flow
- No signal from short T1 tissues

Advantages of TOF-MRA over PC-MRA

- Shorter acquisition time.
- No prior knowledge about flow rates required

Phase mismapping = ghosting

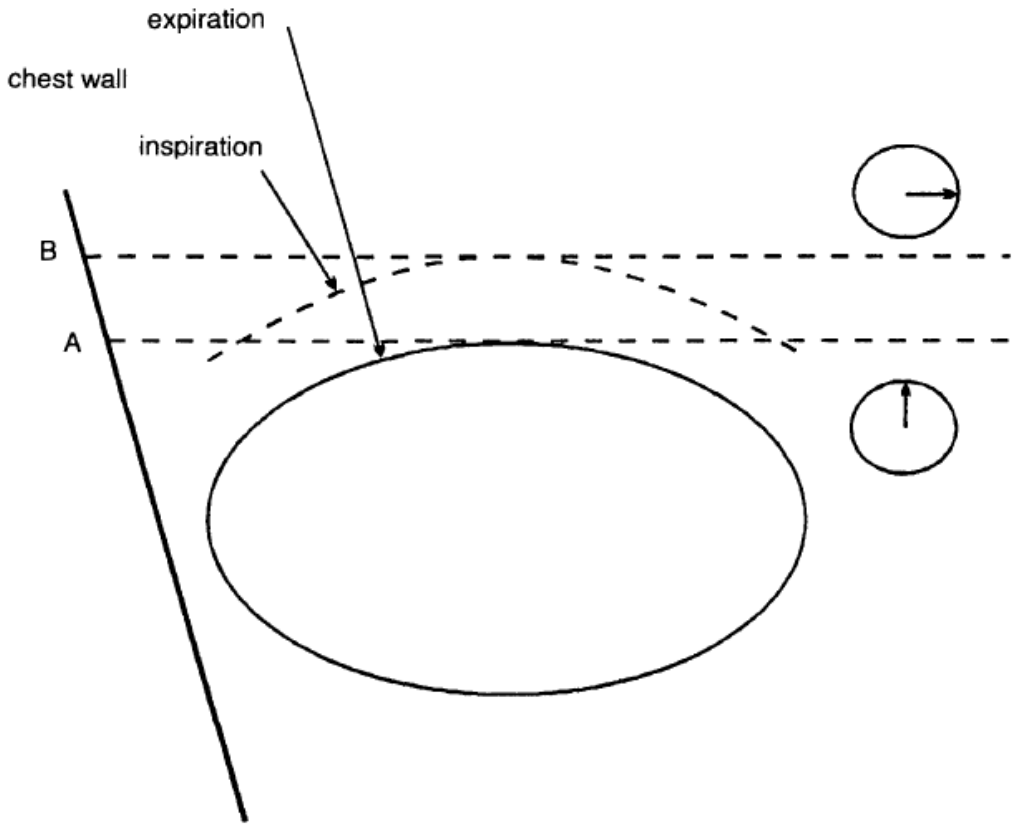
Cause:

Anatomy is moving along a gradient during the pulse sequence (across the phase encoding gradient)

Explanation (look at graph)

the chest wall is located at position A during one phase encoding (expiration), but may have moved to position B during the next phase encoding (inspiration).

Two different phase values are given to chest wall →moving anatomy is mismapped into the FOV.



Causes:

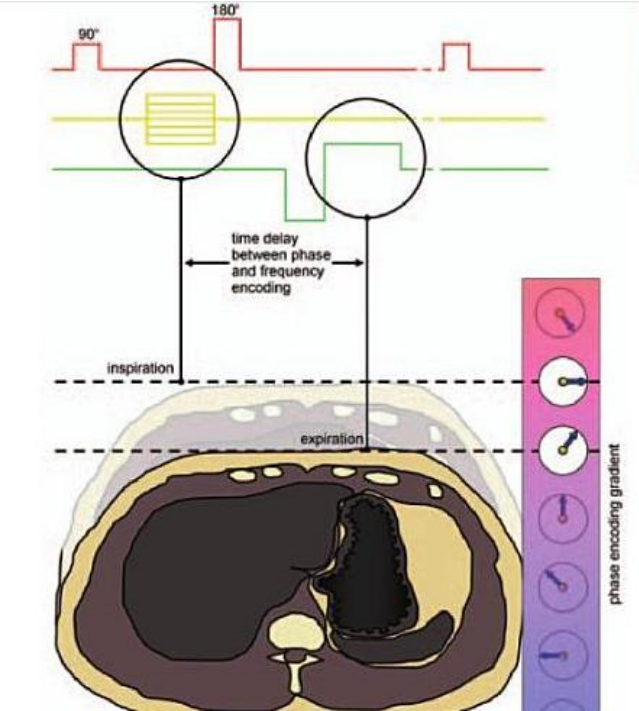
Any structure that moves during the acquisition of data, e.g. chest wall, pulsatile movement of vessels, swallowing, eye movement.

Important note:

Phase mismapping always occurs along the phase encoding axis, due to:

1) inherent time delay between phase encoding and signal readout
2) No mismapping occurs along the frequency axis as frequency encoding is performed as the signal is read
3) motion between each phase encode.

When looking at an image, the direction of phase encoding can be determined by the direction of the phase mismapping or ghosting artefact



- ***The remedy:***

1) As ghosting only occurs along the phase axis, the direction of phase encoding can be changed, so that the artefact does not interfere with the area of interest.

For example:

Sagittal lumbar spine: frequency encoding is usually performed by the Z gradient (head to foot) , Phase is performed by the Y gradient.

Pulsatile motion of the aorta along the phase axis produces ghosting over the spinal cord.

Swapping phase and frequency encodings places the artefact head to foot so that it does not obscure the spinal cord.

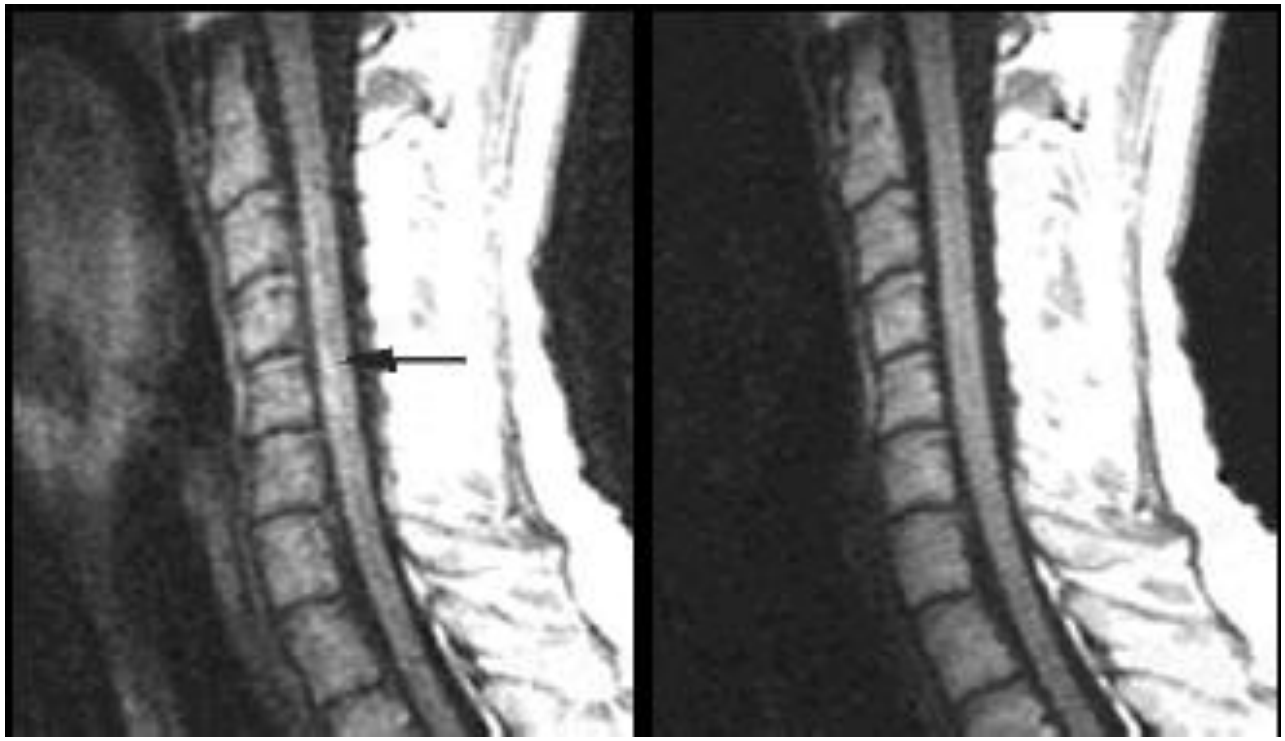
2) Presaturation: of areas producing artefacts

examples:

aorta

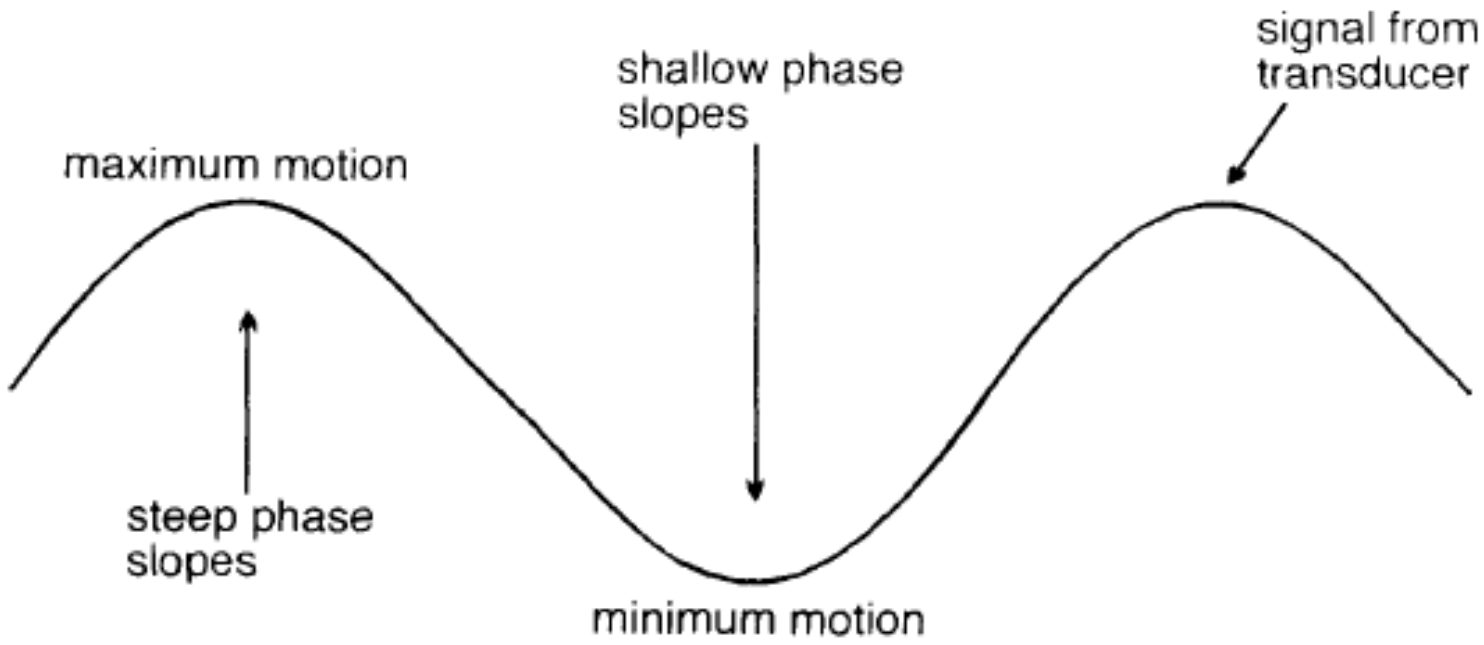
over the throat to decrease swallowing artefacts

over the cervical spine



*3) respiratory compensation (*respiratory ordered phase encoding)*:*

- greatly reduces ghosting from respiration.
- Achieved by placing a set of bellows around the patient's chest when imaging the chest or abdomen.
- These bellows contract as the patient breathes.
- The bellows are connected to a transducer located that converts the mechanical motion of air to electrical signal.
- The system therefore analyses this signal, the amplitude of which corresponds to the maximum and minimum motion of the chest wall during respiration.
- The system is able to perform the shallow phase encoding gradient slopes when the chest wall movement is at a minimum, so that most of the data which provides image signal is acquired when chest wall motion is low.
- It reserves the steep phase encoding slopes for when the chest wall movement is at a maximum

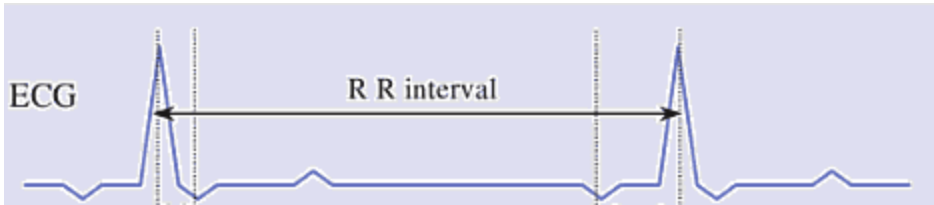


4) respiratory gating:

- Times the excitation RF with a certain phase of respiration.
- Each slice of the acquisition is therefore obtained at the same phase of respiration.
- Disadvantage:
  - First, the TR and therefore the contrast is determined by the rapidity of respiration
  - respiratory rates are longer than the TR→ scan time is lengthened
- Rarely used

5) Cardiac gating:

- monitors cardiac motion by coordinating the excitation pulse with the R wave of systole.
- There are two forms of gating.
  - (1)*ECG gating uses electrodes and lead* wires that are attached to the patient's chest to produce an ECG.
  - (2) *Peripheral gating uses a light sensor attached to the patient's finger* to detect the pulsation of blood through the capillaries. The pulsation is used to trigger the excitation pulses so that each slice is acquired at the same phase of the cardiac cycle.
- Peripheral gating is not as accurate as ECG gating, so is not very useful when imaging the heart itself. However, it is effective at reducing phase mismapping when imaging small vessels or the spinal cord.



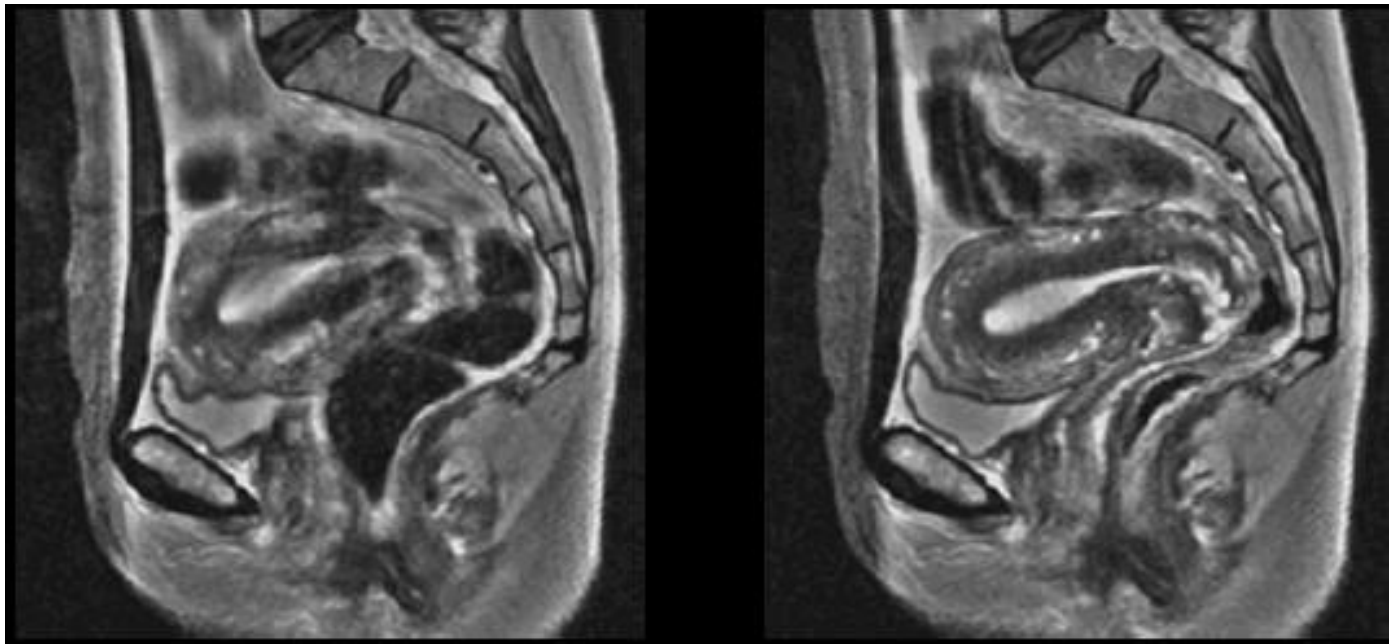
6) Gradient moment nulling (CB4):

7) Bowel motion can be reduced by giving the patient an anti-spasmodic agent prior to the scan when imaging the abdomen or pelvis.

8) Increasing the NEX may help (increases the number of times the signal is averaged)

9) Immobilizing the patient them with pads and straps.

10) In extreme cases, sedation of the patient may be required.



Aliasing or wrap around

Definition:

- artefact produced when anatomy that exists outside the FOV is mapped inside the FOV.

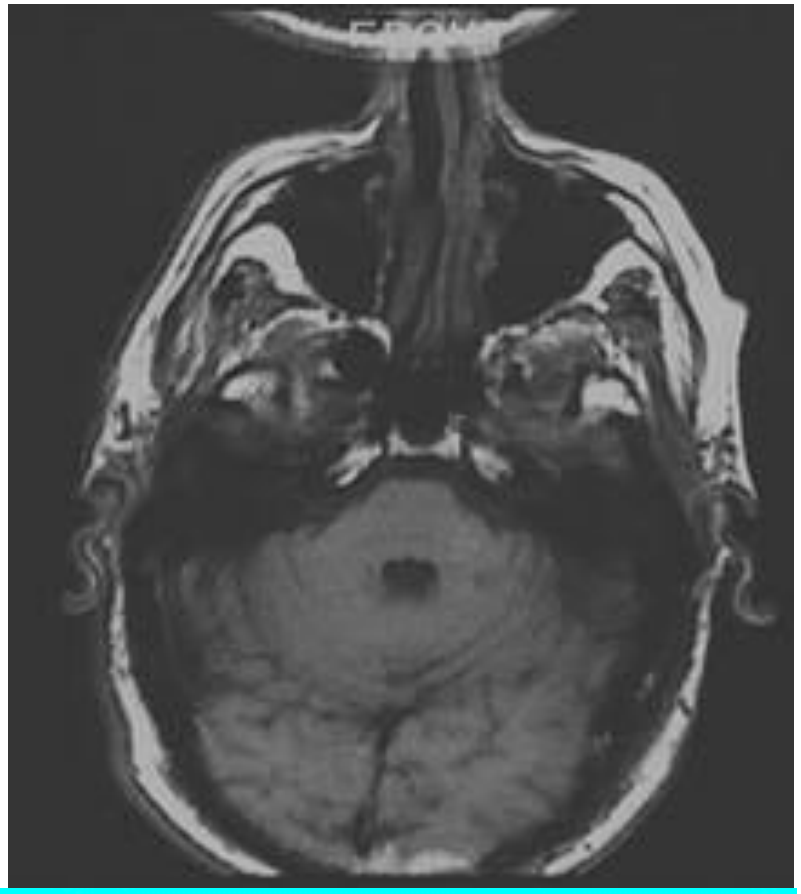
Occurs when:

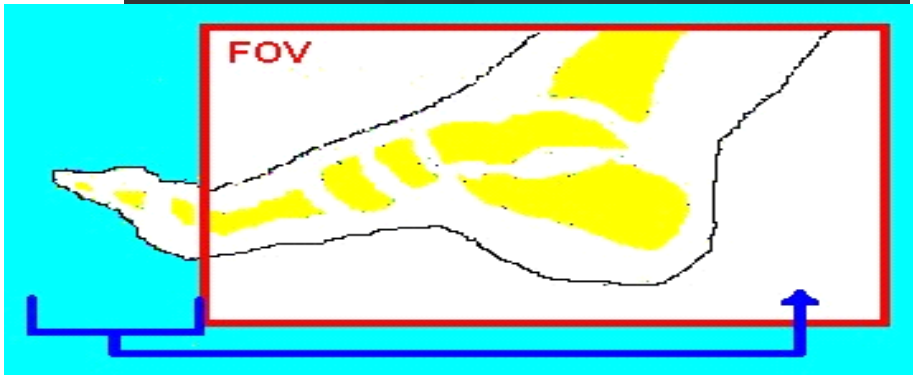
- FOV is smaller the part of body being imaged
- the data is under sampled

Result:

- signal from outside FOV is mismapped into pixels within FOV.

Aliasing can occur along both the frequency and phase axis.





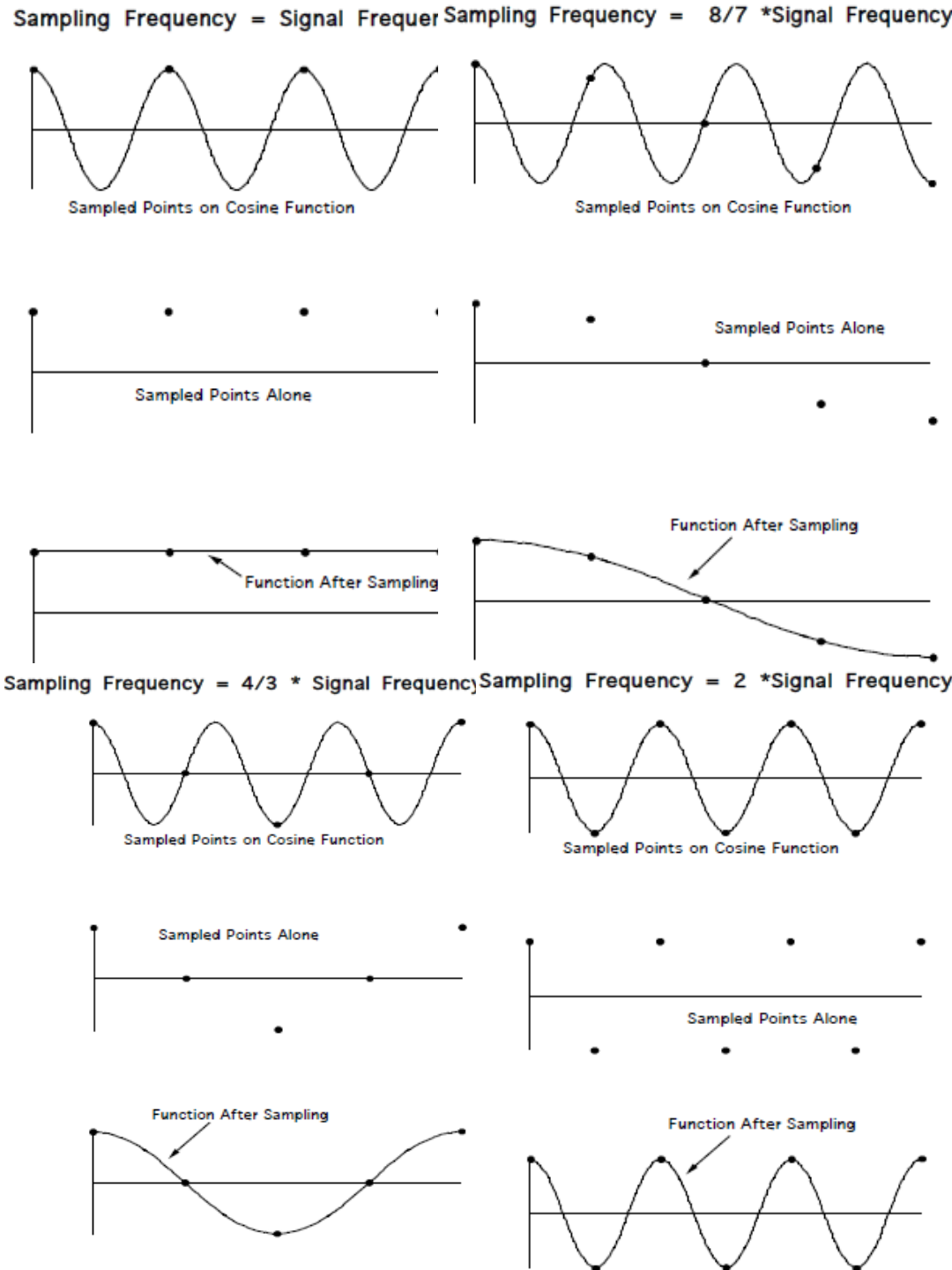
Frequency wrap

Definition:

- Aliasing along the frequency encoding axis

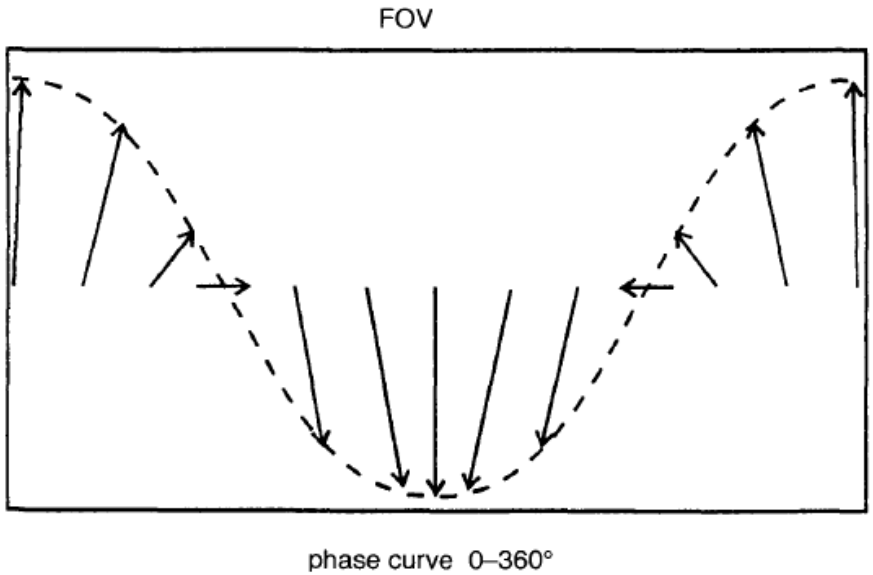
Cause:

- Under sampling the frequencies that are present in the echo.
- If the Nyquist theorem is not obeyed, the frequencies are under sampled and signal from anatomy outside the FOV in the frequency encoding direction is mapped into the FOV

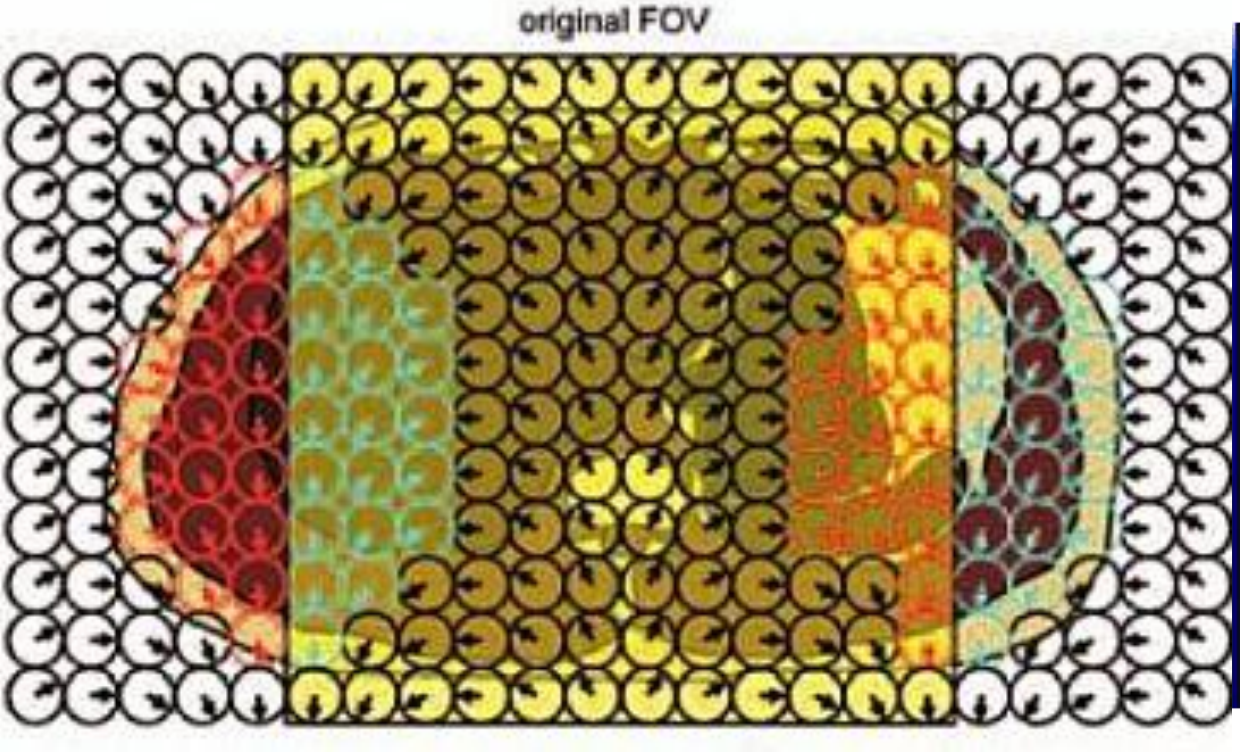


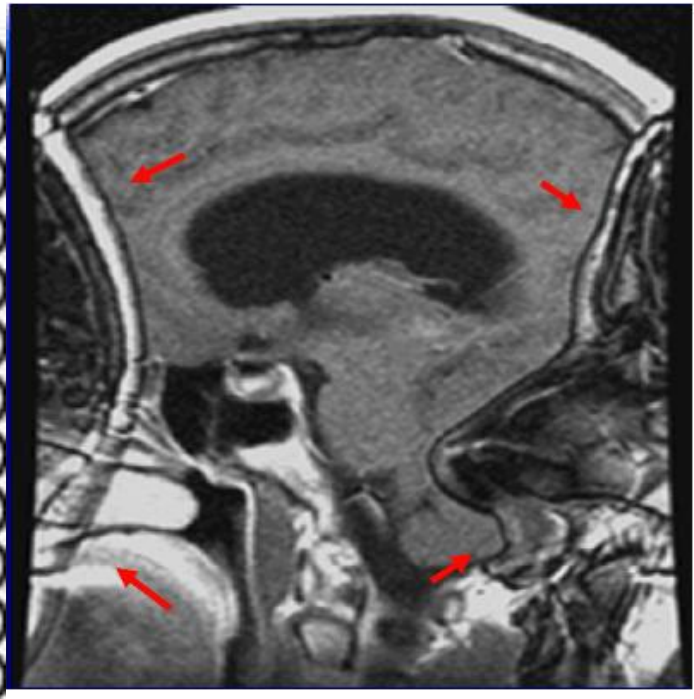
Phase wrap

- Aliasing along the phase axis of the image
- caused by under sampling along the phase axis.
- every phase value from 0-360° (or 12 o'clock through to the following 12 o'clock) must be mapped into the FOV in the phase encoding direction
- This phase curve is repeated on both sides of the FOV along the phase axis.
- As the curve is repeated, signal originating outside the FOV in the phase direction is allocated a phase value that has already been given to signal originating from inside the FOV. (duplication of phase values)→phase wrap along the phase axis.



Explanation:



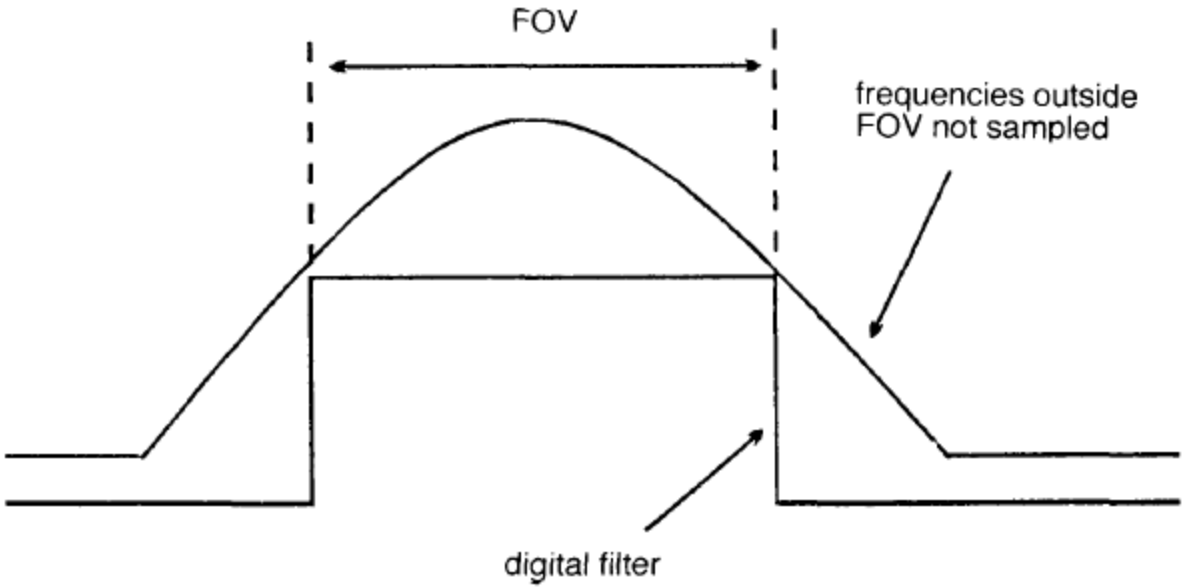


Anti-aliasing along the frequency axis= no *frequency wrap:*

Idea:

- *uses digital* RF pulses to cut off signal frequencies at the edges of the FOV along the frequency encoding axis.
- Signal originating from outside the FOV along is therefore filtered out of the echo
- Most systems automatically apply no frequency wrap.

N.B. Enlarging the FOV so that all the anatomy producing signal is incorporated within the FOV achieves aliasing compensation, but also results in a loss of spatial resolution.



Anti-aliasing along the phase axis = no *phase wrap:*

***Idea**:*

- *oversampling along* phase encoding axis
- *achieved by enlarging FOV in phase direction* →phase curve extends *over a wider area.*
- *There is* now no duplication of phase values (signal outside FOV has different phase values)

Problem:

- *enlarging the* FOV results in a loss of spatial resolution,

Solution:

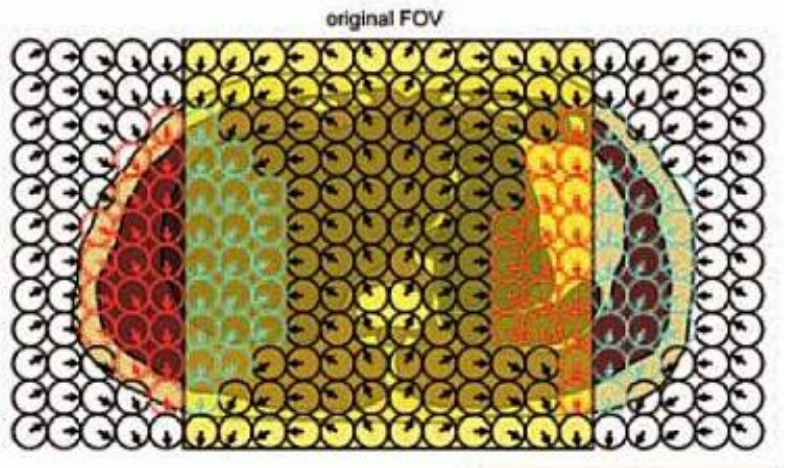
- number of phase encodings is increased to compensate for this.

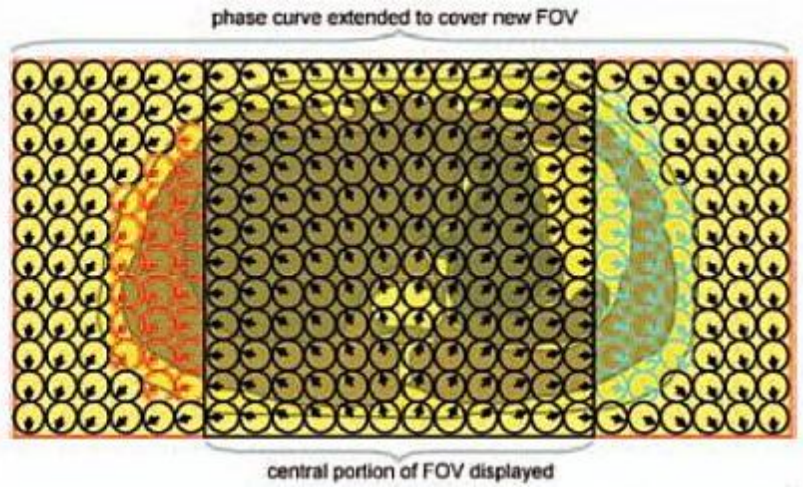
Problem:

- Increasing the number of phase encodings, increases the scan time

Solution:

- some systems automatically reduce the NEX to compensate for this (There is *however* no noticeable reduction in SNR, as the increased number of phase encodings results in more data collection, which tends to offset the reduction in NEX).
- extended portion of FOV is discarded during reconstruction →only selected FOV is displayed
- image quality may suffer Slightly with no phase wrap. As reduction of the number of signal averages, motion artefacts may be more apparent.





Chemical shift artefact

Background:

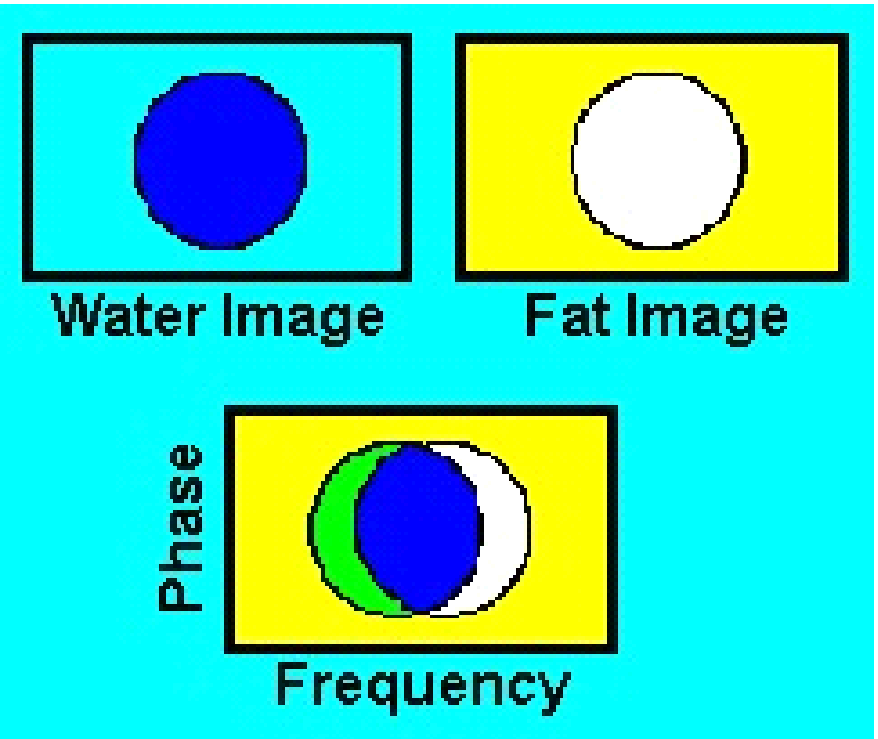
- fat precesses at a lower frequency than water (why?)
- This difference in precessional frequency is proportional to the main magnetic field strength Bo:
  - at 1.5 T the difference = 220 Hz
  - At 1.0 T this difference is 147Hz
  - at lower field strengths (0.5 T or less), it is insignificant.
- At higher field strengths, this can lead to an artefact known as *chemical shift.*

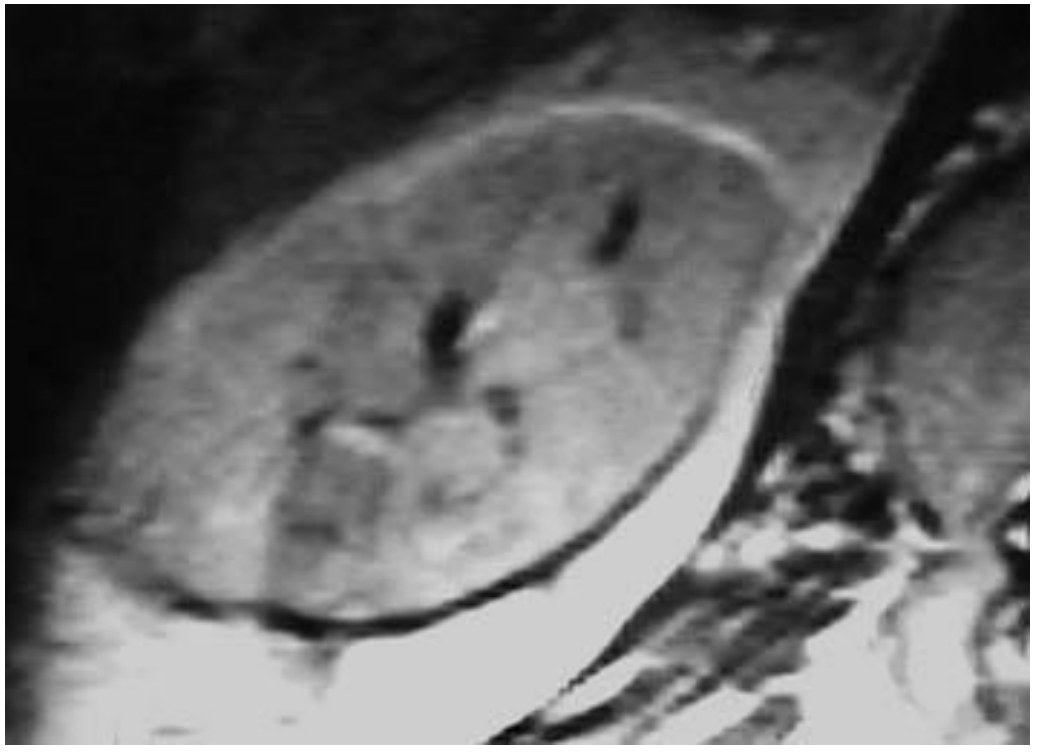
Explanation:

- In the frequency direction, the MRI uses the frequency of the signal to indicate spatial position.
- Since water has a different frequency than fat, the MRI scanner mistakes the frequency difference as a spatial (positional) difference.
- As a result, fat containing structures are shifted in the frequency direction from their true positions.
- i.e. The different resonant frequency of fat & water is transformed into spatial difference.

Common in:

- vertebral bodies, orbits, solid organs surrounded by fat.





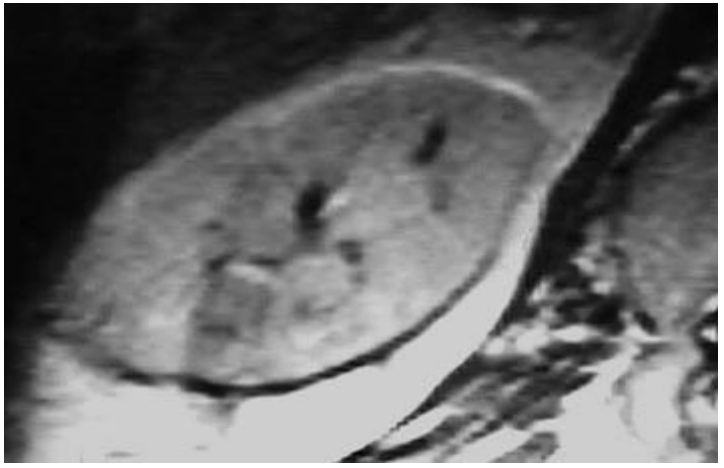
Chemical shift and field strength

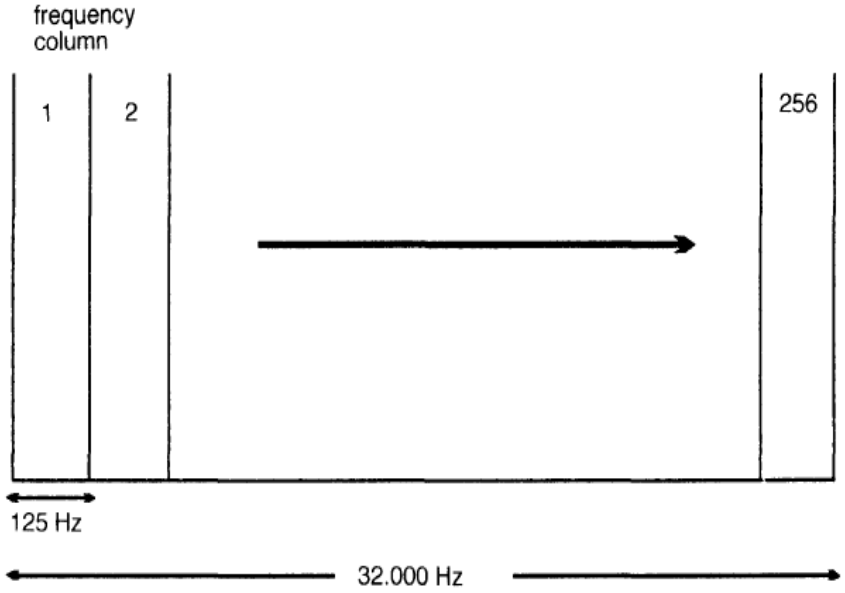
- Worst at higher field strength,
- The amount of chemical shift is often expressed in units known as parts per million (ppm) of the main magnetic field strength.
  - It's value is always independent of the main field strength and equals 3.5 ppm
  - Chemical shift between fat and water can be calculated at different field strengths.

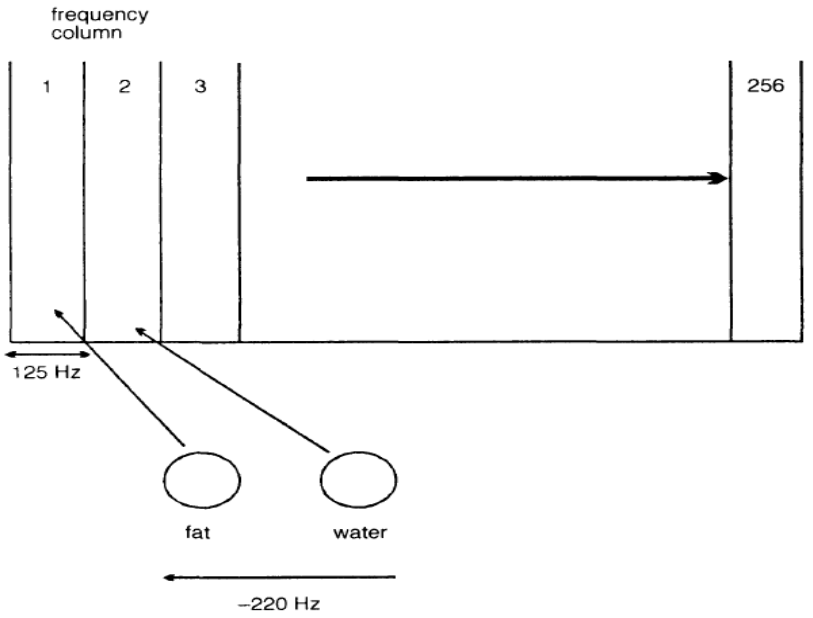
Appearance of chemical shift artefact in MRI images:

- a dark edge at the interface between fat and water (pixel shift of fat relative to water)

Chemical shift artifact always occur along the Frequency-encoding direction





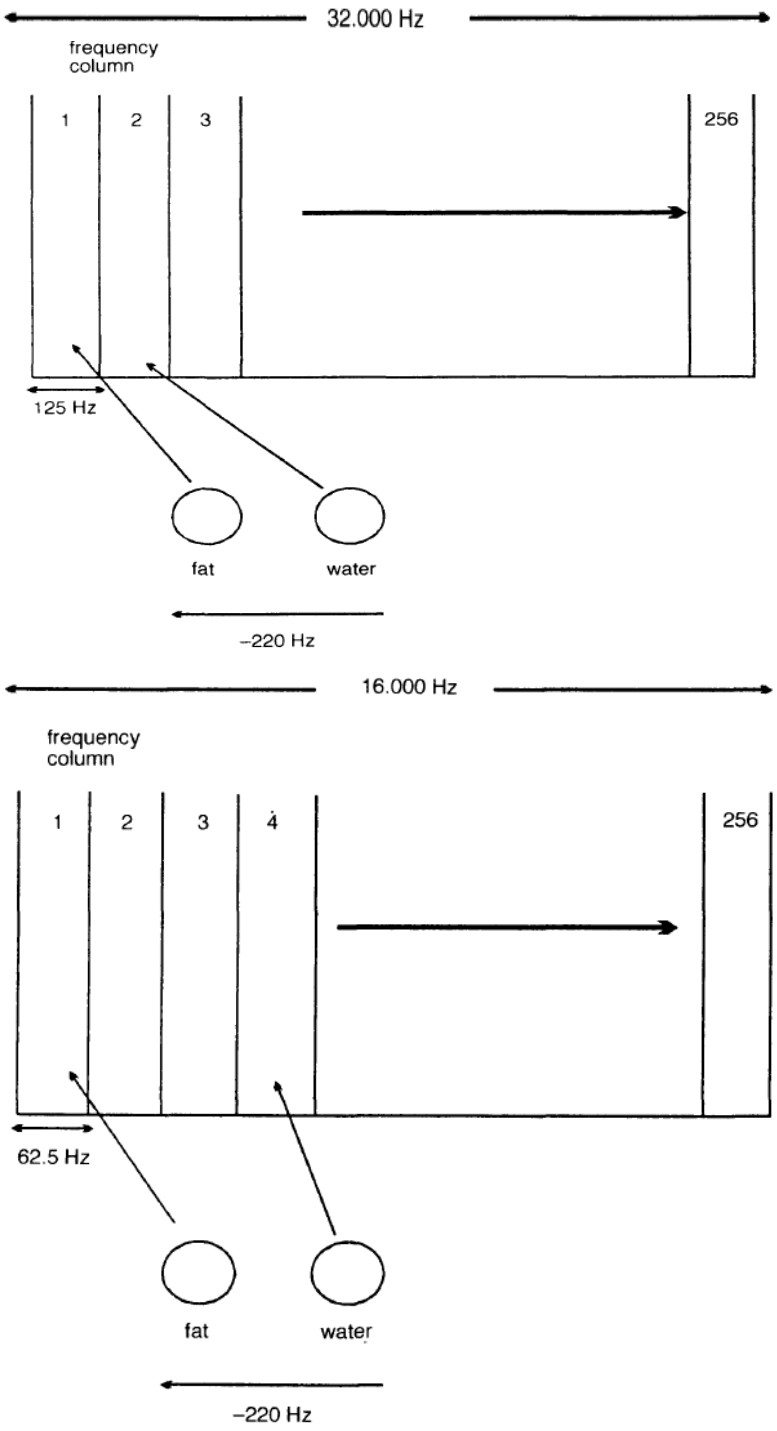


Chemical shift and receive bandwidth

- The receive bandwidth determines the range of frequencies that must be mapped across the FOV.
- The FOV is divided into pixels, and If 256 frequency samples are selected, the receive bandwidth must be mapped across 256 pixels in the FOV.
- bandwidth of each pixel is determined by The receive bandwidth and the number of frequency samples (pixels)
- Example
  - if the receive bandwidth is 32000 Hz, 256 frequency samples are collected (FOV is divided into 256 frequency columns) →Each column has an individual frequency range of 125 Hz per pixel (32000/256 Hz)
  - At a field strength of 1.5 T, the precessional frequency difference between fat and water is 220 Hz
  - → fat & water protons existing adjacent to one other are mapped 1.76 pixels apart (220/125)

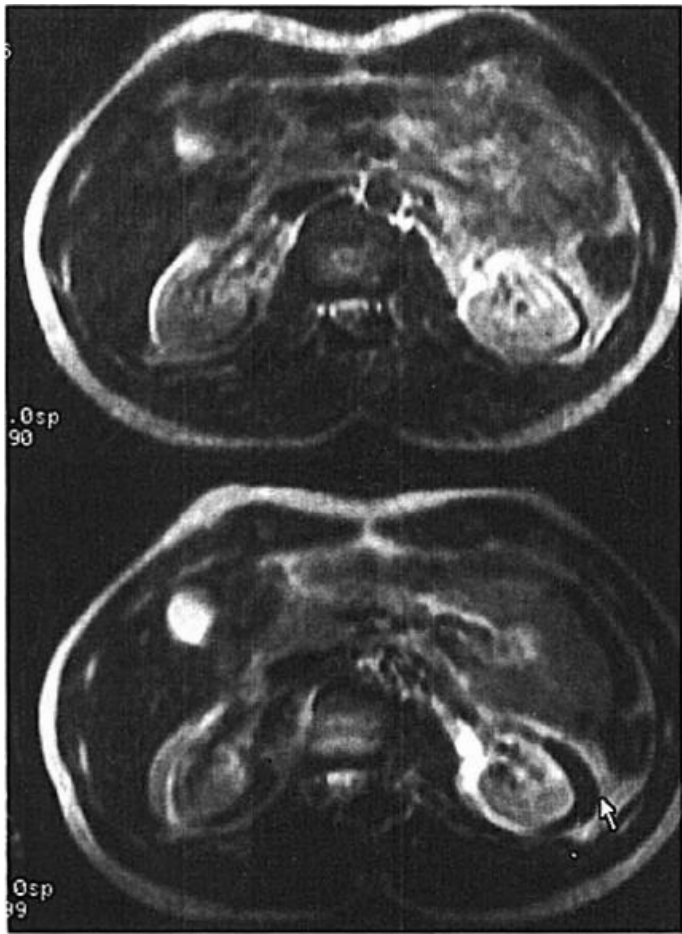
The actual dimensions of this artefact depend on:

- the size of the FOV:
  - As the FOV is enlarged artefact dimension increases.
  - For example, a FOV of 24 cm and 256 frequency columns results in pixels 0.93 mm in size. A pixel shift of 1.76 results in an actual chemical shift between fat and water of 1.63 mm (0.93 x 1.76 mm).
- Receive bandwidth:
  - ↓receive bandwidth → ↑artefact dimension
  - As the receive bandwidth is reduced, a smaller frequency range must now be mapped across the same number of frequency columns, → difference in precessional frequency between fat and water is translated into a larger pixel shift
- Bo strength: see before



Chemical shift artifact compensation:

- can be limited by:
  - scanning at lower field strengths
  - keeping the FOV to a minimum.
  - use the widest receive bandwidth
  - use chemical saturation to saturate out the signal from either fat or water
- These measures are only necessary at higher field strengths, At 0.5 T or less, chemical shift artefact is insignificant



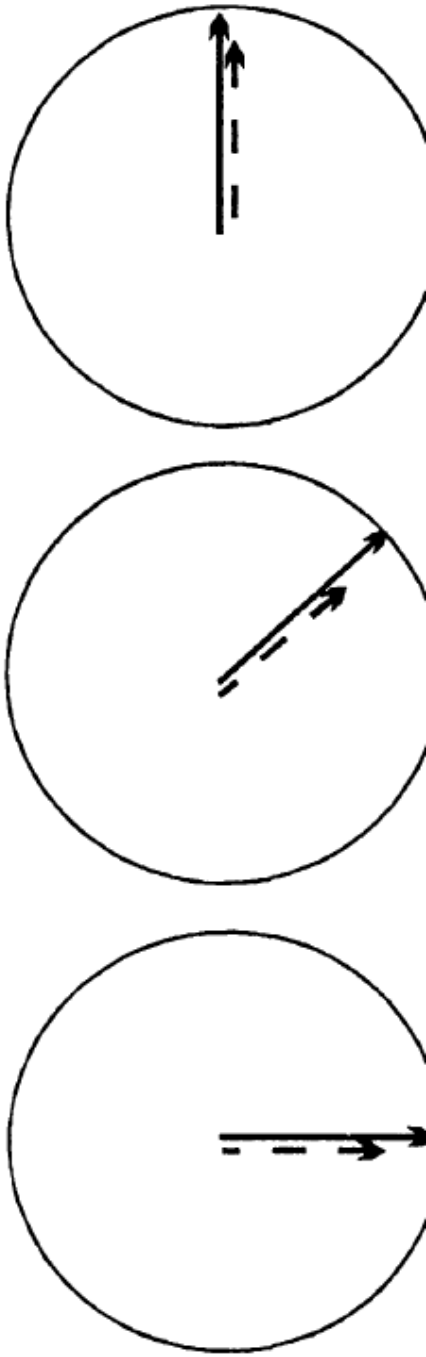
Chemical misregistration artefact

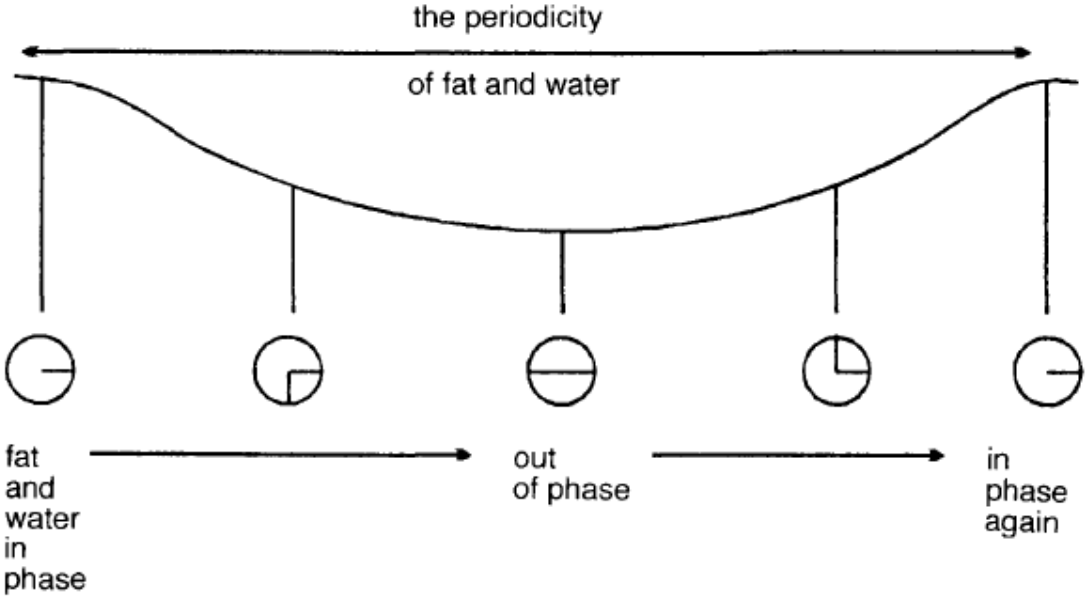
Cause:

precessional frequency difference between fat and water → fat and water are in phase at certain times and out of phase at others,

i.e. they are at various positions on the path but periodically they are at the same position and therefore in phase .

- When fat and water are in phase their signals add constructively, and when they are out of phase their signals cancel each other out
- This cancellation effect is known as *chemical misregistration artefact (*when they are in the same voxel)



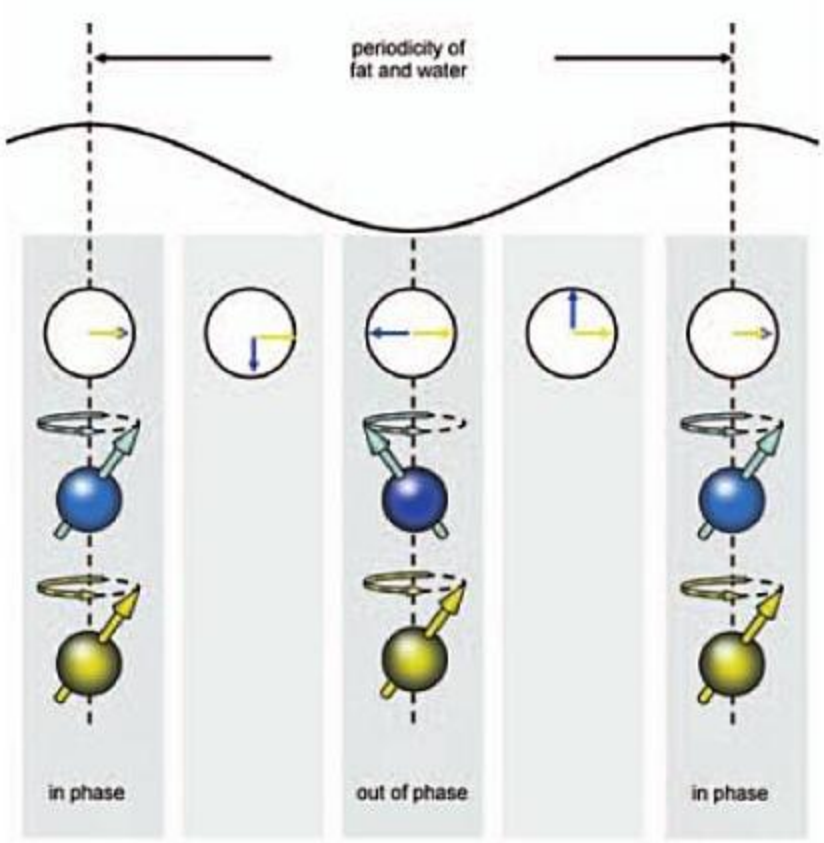


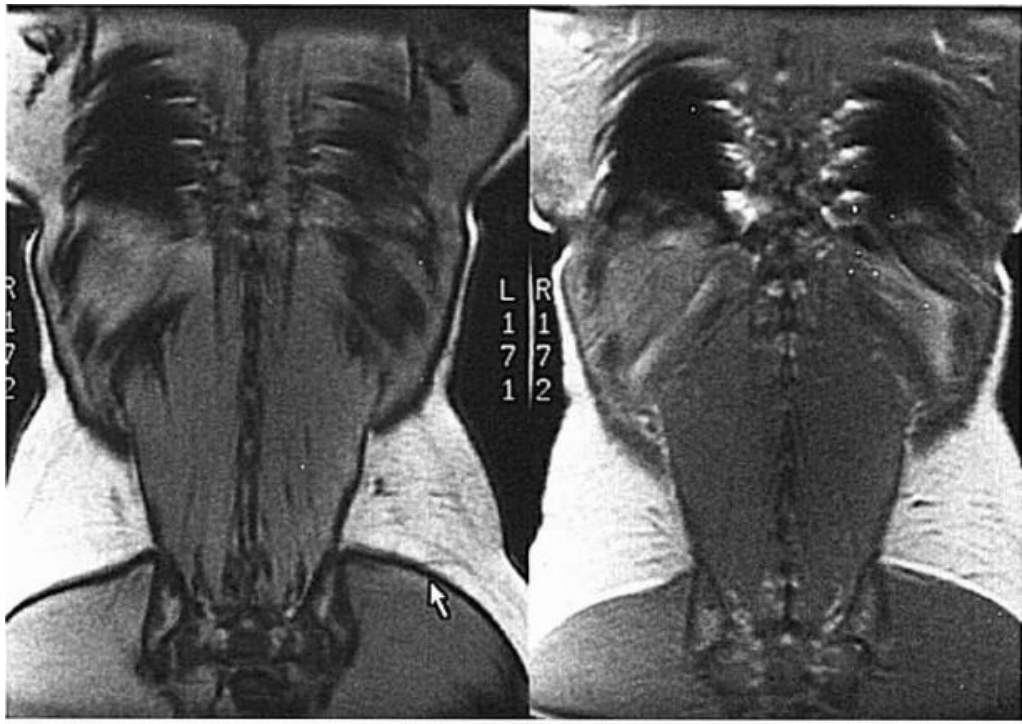
Appearance:

- ring of dark signal around certain organs where fat and water interfaces occur within the same voxel e.g. kidneys
- Chemical misregistration mainly occurs in the phase direction, as it is produced due to a phase difference between fat and water.
- It is most degrading to the image in gradient echo pulse sequences, where gradient rephasing is very ineffective. In spin echo sequences, the 180^{o} rephasing pulse compensates for the phase difference between fat and water, and so chemical misregistration artefact is reduced.

The remedy:

- Use a spin echo sequence to reduce the artefact.
- In gradient echo pulse sequences select a TE that corresponds to the periodicity of fat and water:
  - i.e. TE at which when fat and water are in phase
  - so that their signals add constructively.
  - This depends on the field strength. e.g. At 1.5 T, selecting a TE that is a multiple of 4.2 ms reduces chemical misregistration artefact,
  - at 0.5 T the periodicity of fat and water is 7 ms.






Thank You!